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# Determination of Irrigation Scheduling and Optimal Nitrogen Fertilizer Rate for Onion in Tiyo District, Arsi Zone, South Eastern Ethiopia

Samuel Lindi, Kebede Nanesa, Mehiret Hone, & Bakasho Eticha

1. Ethiopian Institute of Agricultural Research/Kulumsa Agricultural Research Center, Ethiopia

**Abstract:**
The study was conducted at the Kulumsa Agricultural Research Center for three consecutive years. The objectives of this study were to determine optimum irrigation levels and nitrogen rates and investigate their interaction effect on the yield and quality of onion crops. The experiment was arranged in a Randomized Complete Block Design (RCBD) split plot with three replications. The experiment utilized three deficit irrigation levels (100%, 75%, and 50% ETc) were paired with five nitrogen rates ranging from 0 to 184 kg ha-1. The study result of onion bulb yield revealed significant differences at ($p<0.05$). The highest marketable bulb yield (28.66 tons ha-1) was found at 100% ETc and 138 kg ha-1 N fertilizer rate, whereas the lowest yield (16.84 tons ha-1) was found with 50% ETc and no N fertilizer. Water productivity (WP) varied significantly across treatments, with a maximum of 10.9 kg/m³ observed at 50% ETc and 138 kg ha-1 N fertilizer rate, while the minimum (4.42 kg/m³) was recorded at 100% ETc and no N fertilizer. This result highlights the significant interaction between N fertilizer and water levels for onion growth. Yield response factors (Ky) highlighted the sensitivity of onion crops to water deficit. The highest Ky (1.38) was observed at 75% ETc with no N fertilizer. Conversely, the lowest Ky values (0 and 0.26) were observed at 100% ETc with 138 kg ha-1 N and 75% ETc with 138 kg ha-1 N fertilizer rate, respectively. The economic analysis results showed that the treatments receiving nitrogen rates of 46, 92, and 138 kg ha-1 combined with all irrigation levels were significantly profitable. Consistently these treatments surpass a Marginal Rate of Return (MRR) of 100%. Therefore, a nitrogen rate of 138 kg ha-1 combined with irrigation levels of 100% and 75% ETc looks to be a good option for maximizing onion output; nevertheless, interactions of 46 and 92 kg ha-1 nitrogen with all irrigation levels are economically viable in the research area.

*Keywords: Irrigation levels, nitrogen fertilizer rate, onion bulb yield, water productivity*.

## INTRODUCTION

The onion (*Allium Cepa* L.), which is grown in Ethiopia for its tasty leaves and aromatic bulbs, is regarded as one of the major horticulture crops in the world (Mubarak & Hamdan, 2018; Gebretsadik & Dechassa, 2018). Around 38,952.58 hectares were planted with onions in Ethiopia in 2020–2021, yielding 3,460,480.88 tons with an average yield of roughly 8.8 t $ha^{-1}$ (CSA, 2021). This indicated that Ethiopia's onion production (8.8 t $ha^{-1}$) is far lower than the average for the world (18.8 t $ha^{-1}$). A lack of fertilizer, improper spacing, and difficulty obtaining high-quality planting materials coordinated with other cultural techniques can all limit onion production (CSA, 2021). During the "Meher" season, the crop is grown both with rain feeding and with irrigation. The off-season crop, grown with irrigation, makes up a large portion of the territory used for onion production in various parts of the nation. Even in regions where there has been growth, the productivity of onions is still far lower than in other African nations (Yitagesu et al, 2015).

Numerous recent studies have been conducted on the water and nitrogen fertilizer needs of onion crops, as well as the impacts of irrigation levels on yield and yield components, as stated in (Mubarak & and Hamdan, 2018). According to studies by Abdissa et al. (2011) and Tsegaye et al. (2016), a nitrogen fertilizer level of less than 100 kg $ha^{-1}$ was shown to be enough for the production of onions. According to Russo's (2008) findings, the output of onions was not significantly affected by nitrogen fertilizer. Furthermore, it was shown that the onion crop responded to water deficit more moderately throughout the course of the growing season. As a result, it is preferable to divide the water stress across the growing season rather than waiting until the most crucial times for crop growth (Regulated Deficit Irrigation, or RDI) (Kirda, 2000; Kadayifciet al., 2005; Patel and Rajput, 2013). It was discovered that deficit irrigation, applied at various levels (up to 40%), was economically advised. It's possible that the different agro-pedo-climatic contexts of the places they analyzed contributed to the large variation in permissible deficit levels. Put another way, onions cultivated in various soil conditions and with varying crop management practices reacted differently to the application of N fertilizer and deficit irrigation.

As a result, among constantly shifting agro-pedo-climatic circumstances, choosing the ideal N-fertilizer rate and irrigation level is imperative for onion crops. Compared to many crops, onions, and other Alliums are more vulnerable to losing moisture and nutrients due to their shallow and unbranched root systems. Because of this, controlling soil moisture and nitrogen levels is essential to its production (Fitsum et al., 2015). Hence, they require and often respond well to additional fertilizers and supplemental irrigation. In the study area, irrigation is applied without considering the optimum crop water requirements, and the application of nitrogen is also based on the national recommendation which does not take cultivar and soil fertility and moisture regimes. As a result, inadequate management of irrigation water and fertilizer was considered to be an important limiting factor to onion production in the study area. The reasons behind the improper use of water and nitrogen fertilization are that sufficient information on the simultaneous application of water and nitrogen fertilization is not available in the study area. Following the existing problem, this study was conducted to determine the optimum rate of N and required irrigation level for major crops and identify the interactive effect of nutrient and moisture levels on yield and yield quality.

## MATERIALS AND METHODS

### Description of the Study Area

A field experiment was conducted for three consecutive years (2020/21 - 2022/23) at Kulumsa Agricultural Research Center (KARC). KARC is located in the Tiyo district of Arsi Zone, Oromia regional state, Southeastern Ethiopia (Figure 1).

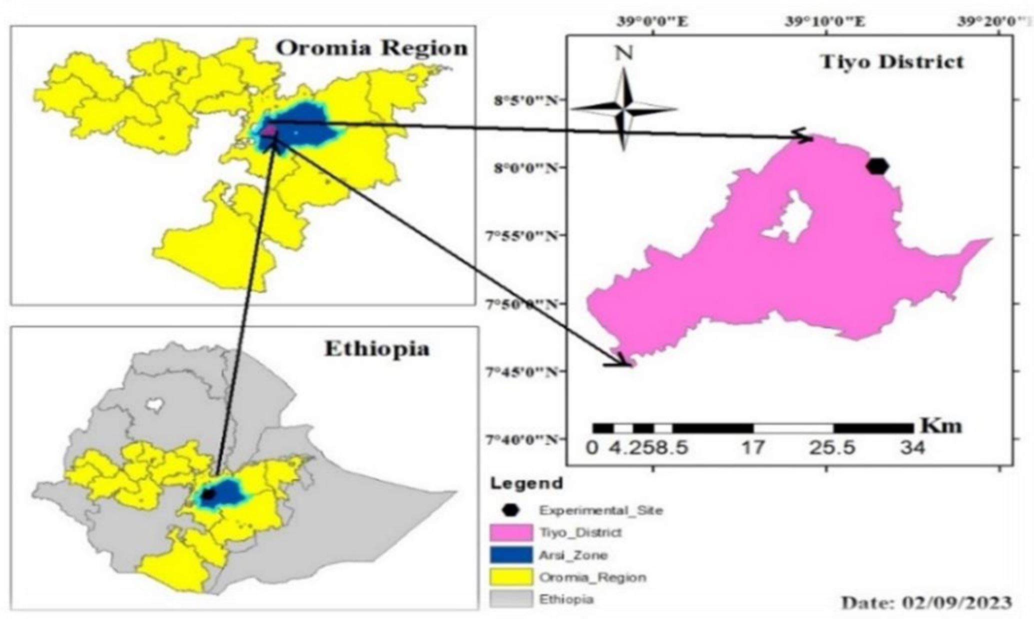


**Figure 1: The map of the study area**

The area receives an average annual rainfall of 821mm and has a uni-modal rainfall pattern. The peak season of the rainfall is from July to August. The average annual minimum and maximum temperatures are 9.9 and 23.1°C, respectively. The soil type is Luvisol/eutricnitosols with a good drainage system (Tafesse, 2003). The coldest month is December whereas March is the hottest month. The experimental site is located 08°00'855" latitude and 039°09'237" longitude and situated at an altitude of 2192 m asl. Effective rainfall and potential evapotranspiration of the cropping season at the study area is shown in figure (2).

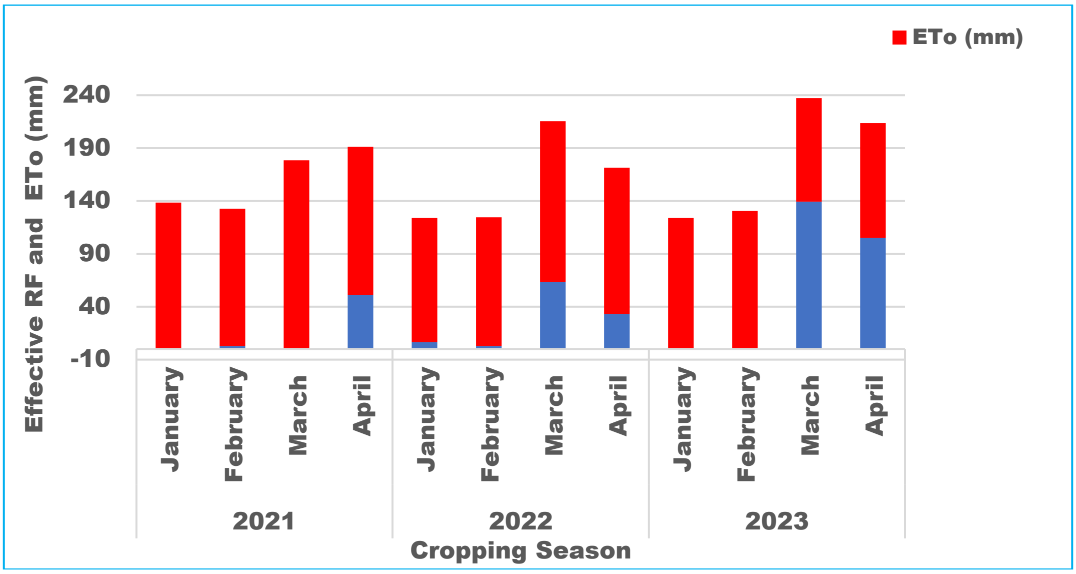


**Figure 2: Effective rainfall and potential evapotranspiration of the cropping season**

**Experimental Design and Procedure**

The experiment was laid out in RCBD split plot arrangement. The treatments were randomized both at the main and sub-plot levels and replicated three times. The deficit irrigation levels were in the main plot while nitrogen fertilizer rate treatments were assigned to the subplots.

**Table 1: Description of treatment combination**

| Treatment | N rate (kg ha-1) | | | | |
|---|---|---|---|---|---|
| **Irrigation level** | **0** | **46** | **92** | **138** | **184** |
| 100% ETc | T1 | T2 | T3 | T4 | T5 |
| 75% ETc | T6 | T7 | T8 | T9 | T10 |
| 50% ETc | T11 | T12 | T13 | T14 | T15 |

## Agronomic Data Collection

The seedlings of onions (*Bombay Red variety)* were raised following proper management practices as suggested by EARO (2004). Seedlings were hardened before transplanting to the main field to enable them to withstand the field conditions. The 45 days healthy and vigorous seedlings were transplanted. After transplanting, three full irrigations were applied uniformly to all plots with three days intervals, to ensure good plant establishment. Immediately after crop establishment, the irrigation was applied to individual plots according to the treatment requirement using a Parshall flume. Urea was used as a source of N; half of the N dose was applied at the time of transplanting and the remaining half was side-dressed after 45 days of transplanting. The P fertilizer was applied uniformly to all plots at the time of transplanting using triple superphosphate. The uniform field management was carried out on all plots as per the recommendations of EARO (2004). The experimental plots inter and intra-row spacing was done based on the recommended agronomic value for onion. Onion is planted on both sides of the ridge; so, transplanting was done on 40 cm, 20 cm, and 5 cm spacing of row plant (plant row spacing across furrow was 40 cm, across the ridge was 20 cm and along the ridge 5 cm between plants). The experimental field was divided into 45 plots and each plot size was 3mx3.5m dimension (10.5m$^2$) area to accommodate six furrows with a spacing of 60 cm and 3.5 m in length. Each plot consisted of five ridges and six furrows. A field channel was constructed for each block to irrigate the field. The amount of irrigation water applied was calculated using CROPWAT 8.0 software by using necessary input data of crop, soil, and climatic data. Irrigation water is applied up to field capacity by monitoring soil moisture content using the daily weather data. Soil moisture was measured before and after irrigation using the gravimetric method. Representative soil samples were taken from the experimental site for chemical analysis (PH, EC, CEC, total available N, OC, and OM) and physical properties (BD, Texture, FC, and PWP).

### *Yield and Yield Component of Onion:*

The height of five randomly selected plants was measured from the ground level to the tip of the longest matured leaf at physiological maturity. The average number of leaves was counted from five randomly selected plants at physiological maturity. In each treatment, bulb diameter was measured at the physiological maturity stage of plants. The total soluble solids were measured from randomly selected bulbs of onion were squeezed into juices and the refractometer reading was recorded after the juices were dropped into the refractometer. The total soluble solid content is expressed in °Brix. The average weight was recorded using a digital balance and a means was reported. Marketable bulb yield was determined by recording the weights of bulbs that are free of mechanical damage, disease and insect pests, and medium to large (20-160 g) from the three central rows and converted into t/ha.

## Determination of Crop Water Requirement

### *Crop water requirement (ETc):*

Crop water requirement (ETc) was calculated from climatic data by directly integrating the effect of crop characteristics into reference crop evapotranspiration. FAO Penman-Monteith method was used for determining reference crop evapotranspiration ($ET_o$). The ratio of $ET_c$ and $ET_o$, called crop coefficients ($K_c$), was used to relate $ET_c$ to $ET_o$ by the equation:

$$\mathrm{ETc} = \mathrm{ETo} * \mathrm{Kc} \quad (1)$$

Where, $ET_c$ = crop evapotranspiration (mm/day), $ET_o$ = reference crop evapotranspiration (mm/day) and $K_c$ = crop coefficient.

Irrigation Requirement (IR) was calculated by the following equation:

$$\mathrm{IR} = \mathrm{CWR} - \text{Effective rainfall} \quad (2)$$

Where, IR in mm, CWR in mm, and effective rainfall which is part of the rainfall that entered into the soil and made available for crop production in mm.

The irrigation schedule was worked out using Cropwat 8.0 software. In the model, one of the computation methods for the optimal irrigation scheduling for no yield reduction is the irrigation given at 100% readily available soil moisture depletion to refill the soil to its field capacity. The readily available water (RAW) was computed by the following formula:

$$\mathrm{RAW} = \mathrm{P} * \mathrm{TAW} \quad (3)$$

Where, RAW is in mm, P is in fraction for allowable soil moisture depletion for no stress, and TAW is total available water in mm.

The total available soil Water (TAW) was computed from the soil moisture content at field capacity (FC) and permanent wilting point (PWP) using the following expression:

$$\mathrm{TAW} = \frac{\mathrm{FC\text{-}PWP}}{100\rho} * (\mathrm{Bd} * \mathrm{Dz}) \quad (4)$$

Where, FC and PWP are soil moisture content at field capacity in (%) on a weight basis, Bd is the bulk density of the soil in gm/cm$^3$, $p$ $is$ density of the water in gm/cm$^3$ and Dz is the maximum effective root zone depth in mm.

Soil bulk density was determined by taking undisturbed soil samples from an effective root zone at 20 cm intervals using a core sampler. The soil samples were oven-dried for 24 hours at a temperature of 105°C. Then, bulk density (ρb) was determined as (equation 5):

$$\mathrm{Bd} = \frac{\mathrm{Ms}}{\mathrm{Vs}} \quad (5)$$

Where, Bd = Soil bulk density (g/cm$^3$), Ms = the mass of soil after oven-dry (g) and Vs = bulk volume of soil (cm$^3$).

The gross irrigation requirement, IRg, in a particular event, was computed from the expression:

$$\mathrm{IRg} = \frac{\mathrm{CWR}}{\mathrm{Ea}} \quad (6)$$

Where, IRg is the gross irrigation requirement in mm, CWR is crop water requirement (mm/day) and Ea is the irrigation water application efficiency in fraction.

**Water Productivity**
Water productivity was estimated as a ratio of bulb yield to the total $ET_c$ through the growing season and calculated using the following equation (8).

$$WP = (Y/ET) \tag{8}$$

Where WP is water productivity (kg/m³), Y crop yield (kg ha-1) and ET is the seasonal crop water consumption by evapotranspiration (m³/ha).

The yield response factor (Ky) was estimated from the relationship equation (9).

$$\left[1-\left(\frac{Ya}{Ym}\right)\right] = Ky\left[1-\left(\frac{ETa}{ETm}\right)\right] \tag{9}$$

Where, Ya=Actual harvested yield, Ym=Maximum harvested yield, Ky=Yield response factor, ETa=Actual evapotranspiration and ETm=Maximum evapotranspiration

The Ky values are crop specific and vary over the growing season according to growth stages with: Ky>1: crop response is very sensitive to water deficit with proportional larger yield reductions when water use is reduced because of stress. Ky<1 the crop is more tolerant to water deficit and recovers partially from stress exhibiting less than proportional reductions in yield with reduced water use. Ky=1: yield reduction is directly proportional to reduced water use.

**Statistical Data Analysis**
Yield and yield components data and water productivity data were subjected to statistical analysis using the R-Software package. Means separation was carried out using the least significance difference (LSD) test at a 5% probability level.

**Partial Budget Analysis**
Economic analysis was conducted to evaluate the comparative advantages of irrigating level and nitrogen fertilizer rate interaction for onion production following the procedure of partial budget analysis set by CIMMYT (1988). The cost that varied during the period of this study was the expense incurred for labor to irrigate experimental plots and cost of fertilizer. The other costs are considered fixed since they hold similar among the experimental treatments. The value of variable cost (VC) was calculated based on the farm gate price of labor. The gross field benefit (GFB) was calculated by multiplying the selling price of the bulb yield of onion. The net benefit (NB) was calculated by subtracting the VC from GFB. The marginal rate of return (MRR) was calculated as the ratio of marginal NB and marginal VC of onion production. The bulb yield of onion was adjusted downwards by 10% before calculation to represent the actual yield that can be attained based on the farmers' practices. The treatments were listed in increasing order of VC. One treatment was discarded from further consideration through dominance analysis due to the greater variable cost, but lower net benefit. The marginal rate of return (MRR) was calculated for the remaining treatments. The acceptable MRR considered declaring profitability in this study was greater than or equal to 100%.

## RESULT AND DISCUSSION

### Soil Physical and Chemical Properties of the Experimental Site

Some selected soil physical and chemical properties of the experimental site are presented in Table 2. Percent of particle size determination revealed that the soil texture of the study area was sandy clay loam. The mean bulk density of soil in the study area was 1.25g/cm$^3$. The pH was computed by Potentiometry (1:2.5 soil: water ratio), where total nitrogen was calculated by Kjeldahl method, OC and OM were analyzed by Walkley and Black while available phosphorus was analyzed by Bray-II method. The mean pH, TN, OC, OM and Available P of the soil of the study area were 6.11, 0.12%, 2.16% and 3.72% and 19.76 mg/kg, respectively. The moisture content at field capacity, permanent wilting point and total available water were 33.6, 21.8%, and 11.8% respectively.

**Table 2: Selected soils physicochemical properties status of experimental sites of Kulumsa**

| **Physical properties** | | | | | | | |
|---|---|---|---|---|---|---|---|
| **BD (g/cm$^3$)** | **Texture** | | | **Soil type** | **FC (%)** | **PWP (%)** | **TAW** |
| 1.25 | **Sand** | **Silt** | **Clay** | Sandy clay loam | 33.60 | 21,8 | 11.8 |
| | 52 | 27 | 21 | | | | |
| **Chemical properties** | | | | | | | |
| **pH** | **TN (%)** | **OC (%)** | | **OM (%)** | | **Av. P (mg/Kg)** | |
| 6.11 | 0.12 | 2.16 | | 3.72 | | 19.76 | |

### Yield and Yield Component of Onion

#### *Plant Height, Leaves Number, Bulb Diameter, and TSS:*

The interaction of different irrigation levels and N-fertilizer rates had a significant impact on plant height. Specifically, the highest plant height of 55.16 cm was observed when the onion crop was subjected to 100% ETc with 184 Kg ha$^{-1}$ N-fertilizer, which was statistically different from all other treatments except for 100% ETc with 138 Kg ha-1 N-fertilizer and 75% ETc with 184 Kg ha$^{-1}$ N-fertilizer. Conversely, the shortest mean plant height of 40.76 cm was recorded when the onion crop was imposed to 50% ETc with 0 Kg ha$^{-1}$ N fertilizer and was statistically inferior than all other treatments. The optimal performance of this growth parameter may be attributed to the fact that larger irrigation levels and fertilizer rates lead to an optimum soil water air balance around the plant root zone and the availability of sufficient soil nutrients. As Doorenbos and Pruitt (1977) noted, water is crucial for maintaining the turgid pressure of plant cells, which is essential for growth. On the other hand, low soil moisture stress may cause the closure of stomata to conserve soil moisture, leading to reduced $CO_2$ and nutrient uptake and hindered photosynthesis and biochemical reactions, ultimately affecting plant growth (Vaux and Pruit, 1983). This finding is in line with the results reported by El-Noemani et al. (2009), who found that soil water supply directly affects plant height growth, and that nitrogen enhances and extends plant vegetative growth (Ambomsa et al., 2023). Additionally, Tadesse et al. (2022) found that plant height increases with irrigation level and N rates.

Analysis of a\variance revealed that the combined application of irrigation levels and nitrogen fertilizer rates had a significant effect on the number of leaves in onion (Table 3). The number of leaves per plant (12.3) significantly improved with the treatment combinations of 100% ETc with 184 kg N ha$^{-1}$ and 75% ETc fertilized with 184 kg N ha$^{-1}$. In the 100% ETc treatment, increasing the N levels to 184 kg N ha$^{-1}$ resulted in a significant increase in leaf number per plant. The lowest mean number of leaves per plant (6.53) was recorded under the treatment 50% ETc with 0 Kg ha$^{-1}$N fertilizer and statistically different from all treatments except 50% ETc with 46 Kg ha$^{-1}$ N-fertilizer, 75% ETc with 0 Kg $ha^{-1}$ N-fertilizer and 100% ETc with 0 Kg $ha^{-1}$ N-fertilizer. The maximum bulb diameter (6.11 cm) was recorded from 100% ETc and 138 kg $ha^{-1}$ N fertilizer rate. The lowest (3.82 cm) bulb diameter was recorded with 50%ETc of irrigation level and no N application (Table 3). With an increase in the level of N from 0 to 138 kg $ha^{-1}$, the bulb diameter of onions increased. The increase in bulb diameter due to an increase in N could be due to the contribution of N to dry matter production and bulb diameter. The present result is in line with the findings of Tekeste et al. (2018), who found a 25% difference in bulb diameter due to the application of 138 kg $ha^{-1}$ N compared with the control treatment. Nasreen et al. 2007 and Guesh (2015) also reported significantly higher bulb diameter due to the application of 120 kg $ha^{-1}$ N. The effects of irrigation level and N rate on TSS were significant ($p<0.05$), as shown in Table 3. The highest (12.30 °Brix) TSS was recorded in the experimental plot treated with 100% ETc and 184 kg $ha^{-1}$ N fertilizer. The lowest (6.53 °Brix) TSS was obtained from the application of 50% ETc with 0 kg $ha^{-1}$ N-fertilizer rates. When the Irrigation level was kept constant, TSS also increased as the N rate increased.

**Table 3: Results of irrigation and nitrogen levels on plant height, leaves number, bulb diameter, and TSS**

| Treatments | Plant Height (cm) | Leaves Number | Bulb diameters (cm) | TSS ($^{Brix}$) |
|---|---|---|---|---|
| 100% ETC*0 N | 46.10$^{fg}$ | 6.87$^{fg}$ | 4.64$^{hfg}$ | 7.60$^{fg}$ |
| 100% ETC*46 N | 48.34$^{ef}$ | 8.61$^{fegd}$ | 5.53$^{bc}$ | 8.61$^{def}$ |
| 100% ETC*92 N | 51.32$^{cd}$ | 9.8$^{fbecd}$ | 5.69$^{ba}$ | 9.80 $^{cd}$ |
| 100% ETC*138 N | 53.72 $^{ab}$ | 11.31$^{ba}$ | 6.11$^{a}$ | 11.31 $^{ab}$ |
| 100% ETC* 184N | 55.16$^{a}$ | 12.30$^{a}$ | 4.95$^{def}$ | 12.30$^{a}$ |
| 75% ETC*0 N | 43.31$^{h}$ | 7.6$^{fg}$ | 4.29$^{h}$ | 6.87$^{g}$ |
| 75% ETC*46 N | 46.97$^{gf}$ | 8.4$^{fed}$ | 4.69$^{hfg}$ | 8.40$^{e}$f |
| 75% ETC*92 N | 49.85$^{cde}$ | 9.77$^{fbecd}$ | 5.23$^{ecd}$ | 9.77cd |
| 75% ETC*138 N | 52.09$^{bc}$ | 10.40$^{bc}$ | 5.32$^{bcd}$ | 10.40$^{bc}$ |
| 75% ETC* 184N | 53.81$^{ba}$ | 12.22$^{a}$ | 5.23$^{ecd}$ | 12.22$^{a}$ |
| 50% ETC*0 N | 40.76$^{i}$ | 6.53g | 3.82$^{i}$ | 6.53$^{g}$ |
| 50% ETC*46 N | 44.80$^{gh}$ | 8.27$^{feg}$ | 4.47$^{hg}$ | 8.26$^{ef}$ |
| 50% ETC*92 N | 47.66$^{ef}$ | 9.47$^{fecd}$ | 4.84$^{ef}$ | 9.47$^{cde}$ |
| 50% ETC*138 N | 49.39$^{de}$ | 10.13$^{bcd}$ | 5.16$^{ecd}$ | 10.13$^{bc}$ |
| 50% ETC* 184N | 51.08$^{cd}$ | 9.97$^{becd}$ | 5.24$^{ecd}$ | 9.97$^{c}$ |
| **LSD (0.05)** | **1.06** | **1.23** | **0.30** | **1.23** |
| **CV (%)** | **1.29** | **19.43** | **3.58** | **19.43** |

This means values in columns and rows followed by the same letter are not significantly different at $P< 0.05$, LSD = least significant difference; and CV= coefficient of variation in percent.

### Average Bulb Weight and Bulb Yield

The interaction effect of irrigation level and N rate on the average weight of onion bulbs was significant ($p<0.05$) (Table 4). The average bulb weight of onion initially increased with increasing irrigation levels and nitrogen rates, but declined at higher levels of irrigation and N rates. However, both the magnitude and pattern of increase or decrease were not the same at all N and irrigation levels. Thus, at 46 kg N $ha^{-1}$, increasing irrigation levels from 50 to 100% ETc increased the mean bulb weight of onion by 19 and 49%, but further increase had no significant effect. Similarly, at 75% ETc, increasing the N rate from 0 to 138 kg N $ha^{-1}$ increased the mean bulb weight by 48 and 25%, while a further increase in N had no significant effect. Similar results were observed for other irrigation levels and N rates. The interaction results showed that the bulb yield of onions was determined by both N rates and irrigation levels. Bulb weight increased with increasing N levels, reaching a maximum at higher N rates in combination with increasing reduced water stress levels. These results were similar to those reported by Worojie et al. (2016). The combined effect of different irrigation levels and N-fertilizer rates showed a significant effect on onion marketable bulb yield. The maximum marketable bulb yield of (28.66 ton/ha) was obtained from 100% ETc with 138 Kg $ha^{-1}$ N-fertilizer, and it was statistically different from all treatments. The lowest marketable bulb yield (16.84 t/ha) was recorded from 50% ETc with 0 Kg $ha^{-1}$ N-fertilizer, which was significantly different from all other treatments. The study results showed that there was an increasing trend in bulb yield with an increase in irrigation level and N fertilizer rate to 138 kg $ha^{-1}$ then it started to decrease. The highest bulb yield obtained with higher irrigation levels was due to the better performance of the growth parameters. The highest level of irrigation and fertilizer rate ensures the optimum growth of the crop by ensuring a balanced water and nutrient supply.

Higher nitrogen and irrigation levels help in the plant's vegetative growth, which enhances the average assimilate accessible for storage and increases the average bulb weight, both of which provide an advantage to raising the marketable bulb yield (Gebregwergis et al., 2016). According to James (2014), when irrigation levels were higher (100 and 120% ETc), the improvement in marketable bulb yield that resulted from increasing the N rate was generally greater than when there was a water scarcity. The increase in vegetative growth and increased assimilate production, which is linked to an increase in leaf area index, bulb diameter, and average bulb weight, may be responsible for the increase in marketable bulb yield caused by the application of nitrogen and irrigation water (Neeraja et al., 1999). This result is consistent with the findings of Bagali et al. (2016) and Quadir et al. (2005). Additionally, Satyendra et al. (2007) found that as irrigation levels rose, bulb output dramatically increased.

**Table 4: Results of Irrigation and nitrogen levels on average bulb weight, marketable bulb yield**

| **Treatme**nts | **Average bulb weight (gm)** | **Marketable bulb yield (ton/ha)** |
|---|---|---|
| 100% ETC*0 N | $67.90^{e}$ | $19.48^{g}$ |
| 100% ETC*46 N | $78.24^{cd}$ | $23.79^{de}$ |
| 100% ETC*92 N | $85.5^{bc}$ | $26.85^{b}$ |
| 100% ETC*138 N | $99.17^{a}$ | $28.66^{a}$ |
| 100% ETC* 184N | $93.61^{a}$ | $27.32^{b}$ |
| 75% ETC*0 N | $62.55^{e}$ | $18.76^{gh}$ |
| 75% ETC*46 N | $71.53^{de}$ | $21.57^{f}$ |
| 75% ETC*92 N | $80.40^{cd}$ | $24.67^{cd}$ |
| 75% ETC*138 N | $92.71^{ba}$ | $26.80^{b}$ |
| 75% ETC* 184N | $90.66^{ab}$ | $25.37^{c}$ |
| 50% ETC*0 N | $52.08^{f}$ | $16.84^{i}$ |
| 50% ETC*46 N | $65.16^{e}$ | $18.36^{h}$ |
| 50% ETC*92 N | $77.87^{cd}$ | $21.72^{f}$ |
| 50% ETC*138 N | $93.30^{ab}$ | $24.10^{de}$ |
| 50% ETC* 184N | $91.50^{ab}$ | $23.41^{e}$ |
| **LSD (0.05)** | **9.11** | **1.07** |
| **CV (%)** | **7.09** | **2.74** |

This means values in columns and rows followed by the same letter are not significantly different at P< 0.05, LSD = least significant difference; CV coefficient of variation in percent.

## Crop Water Requirements, Water Productivity and Yield Response Factor

### *Crop Water Requirement (CWR):*

The seasonal precipitation during the aforementioned period in the experimental area is very low. Hence, it demands the application of irrigation water for crop production to be conducted since the precipitation could not satisfy the onion crop water requirement. Crop water required was calculated using CROPWAT 8 and the computed irrigation amount was applied to meet crop water requirements under the dry conditions. During the growing season 441mm, 331, and 220mm for 100%ETc, 75%ETc, and 50%ETc, crop evapotranspiration (ETc) was applied respectively. It is very important to notice that about 25% and 50% of ETc was saved when 75% and 50%Etc of water were applied in comparison with optimal irrigation treatment (100% ETc). This result is in agreement with the findings of Igbadun et al. (2012) who showed that the water needs of onion crops reduced by about 20% with an increase in irrigation deficit of 50% of reference evapotranspiration.

### *Water Productivity (WP):*

The interaction effect between irrigation levels and N fertilizer rate treatments had a significant ($P \leq 0.05$) influence on the water productivity of onions (Table 5). Both irrigation and N application had a positive effect on the total bulb yield. Water productivity, however, decreased with increasing irrigation depth, whereas N application significantly increased water productivity at all irrigation levels (Table 5). The maximum water productivity (10.9kg/m$^3$) of onion was observed at 50% ETC*138 N ha$^{-1}$ and on the contrary the minimum water productivity (4.42kg/m$^3$) was recorded at 100% ETC*0 N treatment. This shows that the interaction of N fertilizer and water amount is significant for the growth of onion crops. The study result shows that at the same amount of irrigation level of 50% ETc, increasing the fertilizer rate from 46 to 138 kg N/ha increases the water productivity of onion from 8.32 to 10.9 kg/m$^3$ and decreases the relative yield reduction of onion by 20.3%. Similar results were observed for the other irrigation and N combinations. In the current study, it was observed that the water productivity of onion plants was influenced by both irrigation levels and nitrogen rate. The results of the present study are in agreement with the findings of Tayel et al. (2010), who reported maximum water productivity of garlic plants under an N-irrigation combination of 50% ETc + 285 kg N ha-1. These results are also in close agreement with Kebede (2003) and Samson and Ketema (2007), who reported that when irrigation water becomes a limiting factor, yield losses due to reduced soil moisture can be compensated for by water use efficiency.

### *Yield Response Factor (Ky):*

The observed yield response factors (Ky) result of onion for irrigation and N fertilizer level ranged between 0.00 and 1.38. The magnitude of the Ky value indicates the sensitivity of the irrigation protocol for water deficit and subsequent yield decrease. According to Kirda, et al. (2000) the Ky value for field crops goes from 0.2 to 1.15 which agrees with the reported result by Watkinson (2008). From the study result of Table 5 the highest Ky was 1.38 attained at the treatment 75% ETC*0 N of irrigating 75%ETc without N fertilizer. The higher Ky values could be an indication of the severity of water deficit and fertilizer rate at onion bulb yield. The lowest result of yield response factors of 0 and 0.26 was observed at the treatment receiving 100%ETc*138N/ha followed by 75% ETC*138 N, respectively. This demonstrated the optimal response of water and fertilizer amount on onion yield. This means that the rate of relative yield decline caused by water reduction is proportionally smaller than the rate of relative evapotranspiration deficit. According to the results of Table 5, a moisture deficit of more than 25% combined with a fertilizer rate of less than 92kg ha-1 N results in a yield reduction of 24.74 to 34.54%. (Table 5).

**Table 5: Crop and irrigation water requirement, water productivity and yield response factor**

| Treatments | Bulb Yield (kg ha-1) | CWR (mm) | WP (Kg/m$^3$) | Relative water saved (%) | Relative yield reduction (%) | Ky |
|---|---|---|---|---|---|---|
| 100% ETC*0 N | 19,480 | 441.6 | 4.42$^{i}$ | - | 32.03 | - |
| 100% ETC*46 N | 23,790 | 441.6 | 5.40$^{gh}$ | - | 16.99 | - |
| 100% ETC*92 N | 26,850 | 441.6 | 6.09$^{g}$ | - | 6.32 | - |
| 100% ETC*138 N | 28,660 | 441.6 | 6.50$^{ef}$ | - | - | - |
| 100% ETC*184N | 27,320 | 441.6 | 6.20$^{fg}$ | - | 4.68 | - |
| 75% ETC*0 N | 18,760 | 331.2 | 5.66$^{h}$ | 25 | 34.54 | 1.38 |
| 75% ETC*46 N | 21,570 | 331.2 | 6.51$^{e}$ | 25 | 24.74 | 0.99 |
| 75% ETC*92 N | 24,670 | 331.2 | 7.45$^{cd}$ | 25 | 13.92 | 0.56 |
| 75% ETC*138 N | 26,800 | 331.2 | 8.08$^{b}$ | 25 | 6.49 | 0.26 |
| 75% ETC*184N | 25,370 | 331.2 | 7.66$^{c}$ | 25 | 11.48 | 0.46 |
| 50% ETC*0 N | 16,840 | 220.8 | 7.63$^{e}$ | 50 | 41.24 | 0.82 |
| 50% ETC*46 N | 18,360 | 220.8 | 8.32$^{d}$ | 50 | 35.94 | 0.72 |
| 50% ETC*92 N | 21,720 | 220.8 | 9.84$^{b}$ | 50 | 24.21 | 0.48 |
| 50% ETC*138 N | 24,100 | 220.8 | 10.91$^{a}$ | 50 | 15.91 | 0.32 |
| 50% ETC*184N | 23,410 | 220.8 | 10.60$^{a}$ | 50 | 18.32 | 0.37 |

## Partial Budget Analysis

The treatments receiving the fertilizer rate of 46, 92, and 138kg of N/ha at all levels of irrigation amount were found economically profitable (Table 6) because they gave Marginal Rate of Return (MRR) over 100%. On the other hand, the treatments receiving the fertilizer rate of 0 and 184kg N at all levels of irrigation amount were economically dominated (Table 6) because they gave less than 100%MRR. The maximum benefit of 33.51 birr for every birr investment in labor and fertilizer was attained from the application of 138kg N/ha fertilizer at 100%ETc followed by 50% ETc with fertilizer amount of 92 kg N/ha, which gave 33.00 birr return for every birr investment (Table 6). Irrigating the optimum amount of irrigation water with the application of 46kg ha-1 of N also provided an equivalent economic return of 32.49 birr for every birr investment (Table 6).

**Table 6: Partial budget analysis based on mean values for onion production using different levels of N fertilizer and irrigation amount at Kulumsa**

| Treatment | Bulb yield (kg ha-1) | Total Variable Cost (ETB/ha) | Net Return (ETB/ha) | MRR (%) |
|---|---|---|---|---|
| 100% ETC*0 N | 19,480 | 6,400 | 821,500 | - |
| 100% ETC*46 N | 22,790 | 10,600 | 957,975 | 3249 |
| 100% ETC*92 N | 25,250 | 14,800 | 1,058,325 | 2389 |
| 100% ETC*138 N | 28,660 | 19,000 | 1,199,050 | 3351 |
| 100% ETC*184N | 27,320 | 23,200 | 1,137,900 | D |
| 75% ETC*0 N | 18,760 | 4,800 | 792,500 | - |
| 75% ETC*46 N | 21,570 | 9,000 | 907,725 | 2743 |
| 75% ETC*92 N | 24,670 | 13,200 | 1,035,275 | 3037 |
| 75% ETC*138 N | 26,800 | 17,400 | 1,121,600 | 2055 |
| 75% ETC* 184N | 25,370 | 21,600 | 1,056,625 | D |
| 50% ETC*0 N | 16,840 | 3,200 | 712,500 | - |
| 50% ETC*46 N | 18,360 | 7,400 | 772,900 | 1438 |
| 50% ETC*92 N | 21,720 | 11,600 | 911,500 | 3300 |
| 50% ETC*138 N | 24,100 | 15,800 | 1,008,450 | 2308 |
| 50% ETC* 184N | 23,410 | 20,000 | 974,925 | D |

## CONCLUSION

The study was conducted at Kulumsa Agricultural Research Center for three consecutive years and aimed to determine the optimum irrigation level and fertilizer rate for onion yield and quality. The experiment assessed three irrigation levels (100%, 75%, and 50% ETc) and five nitrogen rates ranging from (0 to 184 kg $ha^{-1}$) using a split-plot Randomized Complete Block Design with three replications. The study found that 100% ETc with 138 kg $ha^{-1}$ N fertilizer contributed to the highest yield of 28.66 tons/ha, while 50% ETc with 0 kg $ha^{-1}$ N resulted in the lowest yield of 16.84 tons/ha. The interaction between nitrogen fertilizer and irrigation levels significantly affected onion growth. Water productivity varied widely, with the lowest at 100% ETc with 0 kg $ha^{-1}$ N (4.42 kg/$m^3$) and the highest at 50% ETc with 138 kg $ha^{-1}$ N (10.9 kg/$m^3$). The yield response factor highlighted onion's sensitivity to different irrigation and fertilizer rates, with severe impacts observed at 75% ETc with 0 kg $ha^{-1}$ N (Ky of 1.38) and optimal responses at 100% ETc with 138 kg $ha^{-1}$ N (Ky of 0) and 75% ETc with 138 kg $ha^{-1}$ N (Ky of 0.26). Economically, nitrogen rates between 46 and 138 kg ha-1 were profitable across all irrigation levels. Notably, combinations of 138 kg ha-1 nitrogen with 100% or 75% ETc showed the highest Marginal Rates of Return (MRR), making them advisable for maximizing onion yield under irrigated conditions.

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