SOIL & CROP SCIENCES | RESEARCH ARTICLE

Executing legitimate irrigation scheduling by deficit irrigation mechanism to maximize onion production

Babur Tesfaye Yersaw¹ and Tarun Kumar Lohani²*

Abstract: Lack of irrigated water poses a threat in arid and semi-arid areas. Hybrid irrigation system has become an obligatory to save water and increase productivity. Deficit irrigation scheduling is a recent innovative approach of water-saving method. An experiment was conducted to estimate the irrigation interval and find an amicable solution by optimum deficit irrigation level at Arba Minch of southern Ethiopia using conventional furrow irrigation system. The treatments comprised 75%, 50% and 25% of irrigation requirement and four growth stages (initial, development, bulb formation, and late), which were considered in random complete block design with three replications. Refilling was commenced when 25% of Readily Available Water (RAW) depletion at the full irrigation was observed. The irrigation intervals at growth stages were 4, 6, 4, and 3 days, respectively, with an overall irrigation interval of 3 days. The net and gross irrigation of the crop were 311.80 mm and 445.42 mm, respectively. The highest crop phenology and yield were obtained by applying Irrigation Requirement (IR) of a maximum 100% and minimum at 25%. The maximum yield of 25.88 ton/ha was obtained from full irrigation which hardly affects the yield of 25.70 ton/ha obtained from 75%IR at late growth stages. Therefore, application of 100%IR at 3 days interval was assessed as economically

ABOUT THE AUTHOR
Babur Tesfaye Yersaw is a lecturer in Water Resources and Irrigation Engineering and Tarun Kumar Lohani is a Professor in Hydraulic and Water Resources Engineering in Arba Minch University, Ethiopia.

PUBLIC INTEREST STATEMENT
Stage-based deficit irrigation is required where there is enough land but not enough water. Deficit irrigation refers to applying less water than the crop actually requires. Applying deficit irrigation reduces crop yield than that of full irrigation. Full irrigation refers to applying water to the crop’s root zone in a quantity sufficient to meet the crop’s water needs. Deficit irrigation also improves water productivity. Utilizing a unit volume of water to produce yield is referred to as water productivity of a crop. The aim of this study is to determine the appropriate irrigation scheduling and to estimate the effect of deficit irrigation on crop phenology, yield, water productivity, financial feasibility of onion. It is economically feasible because saved water can be used to cultivate more land. Therefore, this technique is suitable for successful utilization of limited water for increasing crop production at arid and semi-arid regions.
productive. However, 50%IR at 3 days interval can be an option when there is a constraint of water supply. The findings will be useful for irrigation water management to maximize crop yields with limited water and unlimited land resources.

Subjects: Agriculture & Environmental Sciences; Soil Sciences; Paleobiology

Keywords: Crop phenology; irrigation scheduling; irrigation requirement; optimum deficit level and readily available water

1. Introduction

Ethiopia enjoys adequate amount of rainfall, but due to sporadic climate change and erratic rainfall, it faces acute shortage of water especially in arid and semi-arid regions. In addition to this, enormous growth of population has reduced the availability of water resources (FAO, 2011; Suhaimi et al., 2021). Therefore, the availability of water for agricultural production decreases. The agriculture sector in those areas is severely impacted by water scarcity (Falkenmark, 2013). Excessive water consumption for plants results from inefficient water use. Farmers are seldom able to forecast an appropriate level of water consumption, which influences the plant quality, resulting to water wastage. Innovative application of deficit irrigation scheduling technologies may improvise in saving ample quantity of water.

Applying deficit irrigation decreases the yield and water productivity (Wakchaure et al., 2018, 2021). In order to increase the yield and water productivity, stage-based deficit irrigation is the best option for irrigation water management. Depriving irrigation in some growth stages of a crop leads to higher yield and water use efficiency. Many studies have shown that there is a significant yield and yield component reduction when onion is stressed at different growth stages. This makes an increase in water use efficiency when moisture stress transpires in some non-sensitive stages. Different crops have different response for moisture stress. Therefore, irrigation scheduling with stage-wise deficit irrigation improves the yield and water productivity.

Irrigation scheduling, which refers to timing and volume of irrigated water, enables farmers to reduce crop water stress, increase crop yields, reduce fertilizer costs by holding overflow, waterlogging, and deep percolation (Harrison et al., 2013). The primary motto of this research is to find an appropriate solution for irrigating precise amount of water in the appropriate time. The objective is to maximize water use efficiency, crop production, and to minimize irrigation costs (Hanson & May, 2004). Optimal irrigation scheduling leads to maximum yields, good bulb quality, and under-irrigation stresses causing losses in total yield and quality (Mintesinot et al., 2004; Ayza, 2018). A perfect irrigation scheduling is predominantly based on; retrieving daily updated data from remote weather stations via wireless technology, historical climatic data to schedule irrigation, and daily ETo using on-site weather measurements. Daily (on-site) ETo measurement are used to determine the real soil moisture (Dukes et al., 2009). Many studies have been conducted on deficit irrigation scheduling on onion crop in Ethiopia, but majority of them were conducted using applying deficit irrigation throughout the growth stages (Ayana, 2011). Some researchers were also used climate data from the preceding years (temperature, wind speed, humidity, rainfall, and solar radiation; Dirirsa et al., 2017; Tolossa & Yildiz, 2021). However, applying deficit irrigation throughout the growth stages didn't always increase the crop yield. Because, the crops were sensitive at some stages and the current climate differs from former and future climatic situations. Therefore, this research provides a platform to find the deficit evapotranspiration-based irrigation scheduling and identifying the sensitive growth stages of onion crop.
2. Materials and methods

2.1. Description of the study area

The field experiment was conducted in Arba Minch city of Southern Ethiopia. Geographically, it is located between the latitudes of 5°40′0″ N to 6°20′0″ N and longitudes 37°20′0″ E to 37°40′0″ E with an altitude of 1203 m above mean sea level (Figure 1).

The average minimum and maximum temperature of the study area was 15.4°C (December) and 33.5°C (March) respectively (Figure 2). The rainfall in the study area follows a bimodal pattern with two peak rainfall seasons one from April to May and the other September to October with average monthly precipitation of 160.6 mm and 125.9 mm, respectively.

2.2. Raising nursery and preparing of experimental field

The seed of Red- Bombay onion variety, an early maturing and high yielding variety of onion (Allium cepa L.), was sown on 13 August 2020, using 10 cm row to row spacing in a well-prepared

Figure 1. Location map of the study area.

Figure 2. Climatic variation of the study area.
seed bed of 1.2 m x 2 m size two number at a seed rate of 175 grams per bed. The nursery bed was slightly covered with soil and mulched with grass after seed sowing. The light irrigations were frequently applied till the seedlings were ready for transplanting. The 45 days old seedlings were transplanted on 28 September 2020, on the top of a ridge in the ridge-furrow system at 10 cm plant to plant spacing and 32 cm furrow to furrow spacing. Only healthy, vigorous, and uniform seedlings were transplanted. About 50 plants were transplanted in each row, and 200 plants in each plot. The distance between treatments and replication were 1 m to protect the influence of irrigation water. The plot size was 1.6 m × 5 m (8 m²) of total area 6.8 m × 58 m (394.4 m²). About 50 plants were planted in each row, 200 plants in each plot totaling 6000 plants.

2.3. Experimental treatments design
The treatment was developed for three irrigation (75, 50 and 25%) and four growth stages (initial, development, bulb formation, and late), which were laid out in random complete block design with three replications (Table 1).

2.4. Irrigation scheduling
When the available water level drops by a percentage known as the Management Allowable Depletion (MAD), irrigation was used with 25% Readily Available Water (RAW) depletion (Shock et al., 2015). RAW refers to the amount of water that can be used without requiring irrigation. The soil moisture content was determined using a pressure plate and a pressure membrane device at FC and PWP with suction of –one-third bar and –15 bar, respectively. It can be calculated by using Equation 1 (Allen et al., 1998).

\[ AW = \frac{(FC - PWP) \times Zr}{100} \]  

(1)

| Treatment | Growth stages | Explanation |
|-----------|---------------|-------------|
| Days from transplanting | G1 | G2 | G3 | G4 |
| Control | 20 | 30 | 30 | 20 |
| 75%IR and full irrigation and full irrigation at other stages | 1 | 0.75 | 1 | 1 |
| T2 | | | | |
| T3 | 1 | 1 | 0.75 | 1 |
| T4 | 1 | 1 | 1 | 0.75 |
| 50%IR and full irrigation at other stages | 1 | 0.5 | 1 | 1 |
| T5 | | | | |
| T6 | 1 | 1 | 0.5 | 1 |
| T7 | 1 | 1 | 1 | 0.5 |
| 25%IR and full irrigation at other stages | 1 | 0.25 | 1 | 1 |
| T8 | | | | |
| T9 | 1 | 1 | 0.25 | 1 |
| T10 | 1 | 1 | 1 | 0.25 |

**N.B.** G1 = Initial stage, G2 = Development stage, G3 = Bulb formation stage, G4 = Late stage, and IR = Irrigation requirement.
where; AW is Available water (mm), FC is field capacity (%), PWP is permanent wilting point (%), and Zr is root depth (mm).

The readily available water was calculated by

\[ \text{RAW} = \text{AW} \times \text{MAD} \]  \hspace{1cm} (2)

where RAW is calculated in mm.

The amount of allowable depletion for onions is about 25–30% of the total available water in the soil. The net irrigation requirement was applied at which soil moisture depleted 25% in control treatment. The root depth and total available water-holding capacity were calculated at each irrigation period using Equation 3 (Allen et al., 1998).

\[ \text{dn} = \text{ETc} - \text{Pe} \]  \hspace{1cm} (3)

where dn is net depth of irrigation (mm), ETc is crop water requirement (mm), and Pe is effective rainfall (mm).

The effective rainfall was determined by comparison of the rainfall with the crop water used (ETc). If the rainfall contributes for soil moisture greater than the crop evapotranspiration, the effective rainfall will be equal to ETc, and if less than the crop evapotranspiration, the effective rainfall is equal to total rainfall.

The crop water requirement is calculated by

\[ \text{ETc} = \text{ETo} \times \text{Kc} \]  \hspace{1cm} (4)

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

The onion crop coefficient values for the beginning, mid, and mature stages were 0.51, 1.04, and 0.95, respectively (Bossie et al., 2009), while onion crop growth lengths were 20, 30, 30, and 20 days, respectively. Based on the crop’s Kc values and the length of each growth stage, the daily crop coefficient was interpolated for the development and maturity stages.

Gross irrigation, the total amount of water applied for irrigation considering deep percolation loses was determined by (Hassene & Seid, 2017)

\[ \text{dg} = \frac{\text{dn}}{\text{Ea}} \times 100 \]  \hspace{1cm} (5)

where dg is gross irrigation (mm), and Ea is irrigation application efficiency (%).

The average value of the estimated application efficiency of the field was found to be 70% (Diotto & Irmak, 2016).

### 2.5. Irrigation water application

After transplanting of seedlings in the experimental area, the canal water from Kulfo River was diverted and brought to the experimental field using a lined tertiary channel. Calibrated pipe with a water flow control gate was installed at the lined canal. The discharge of the calibrated pipe was 2 lts/sec. Geo-membrane was used to protect water losses from a lined canal up to the field canal. Water flows into each plot and the time required to apply the desired depth of water was calculated as soon as water was diverted into the plot. The water inflow into the field was immediately stopped after the desired depth of water was applied. Water flow was carefully controlled to avoid the flow of water into water deficit plots. The time required to deliver the
desired depth of water into each plot from the calibrated pipe was calculated (Equation 6; Kifle, 2018)

\[ t = \frac{dg \times L \times W}{6 \times Q} \quad (6) \]

where \( dg \) = gross depth of water applied (cm), \( t \) = application time (min), \( L \) = furrow length in (m), \( W \) = furrow spacing in (m), and \( Q \) = flow rate (discharge) (l/s)

2.6. Crop agronomic data collection

2.6.1. Plant height (cm)
A meter tape was used to measure plant height from the ground level to the tip of the longest leaf. Five randomly selected plants were measured in the center rows of each plot, and the average was computed at the physiological maturity stage of the crop. It was recorded on a plot-by-plot basis as the number of days from the date of transplanting till 75% of the leaves had fallen down and two-thirds of the leaves had turned yellow. At the active green leaf stage, the number of completely formed leaves of five randomly selected plants was counted, and the average was computed to determine the number of leaves per plant.

2.6.2. Leaf length (cm)
The average length of the longest leaves in five randomly selected plants at maturity was measured.

**Bulb diameter (cm):** During harvest, six randomly selected plants in each plot had their bulb diameter measured at right angles to the longitudinal axis at the widest circumference of the bulb using a veneer caliper.

2.6.3. Bulb length (cm)
Bulb length was determined by using a veneer caliper to measure the vertical average length of the matured bulb of six randomly selected plants in each plot. The yield of the crop was collected and measured using sensitive balance.

3. Optimum deficit irrigation selection indicators

3.1. Estimation of irrigation water saved (WS)
The amount of WS per hectare was obtained by subtracting the amount of water consumption of particular deficit irrigation from the full irrigation requirement (Equation 7; Hassene & Seid, 2017).

\[ WS = \frac{(WFI - WDI) \times 100}{WFI} \quad (7) \]

where \( WS \) = Water saved (%), \( WFI \) = Total water used at full irrigation (mm), and \( WDI \) = Total water used at each deficit irrigation level (mm).

3.2. Additional Irrigable Land (AIL)
The additional irrigable land was estimated by

\[ AIL = \frac{(WFI - WDI) \times 1ha}{WFI} = WS \times 1ha \quad (8) \]

where \( AIL \) = Additional irrigable land (ha), \( WFI \) = Water applied at full irrigation (m³/ha), \( WDI \) = Water applied at deficit level (m³/ha), and \( WS \) = Water saved (m³/ha).

3.3. Additional yield from saved water
The additional yield from saved water was calculated by using Equation 9.
\[
\text{AYS} = \frac{(\text{YS} - \text{WS}) \times 100}{\text{d}_0} \quad (9)
\]

where \(\text{AYS}\) = Additional yield from saved water (Kg/ha), \(\text{YS}\) = Yield from each deficit level (Kg/ha), \(\text{WS}\) = Water saved (m\(^3\)/ha), and \(\text{d}_0\) = Water applied at each deficit level (m\(^3\)/ha).

### 3.4. Yield increment

The yield increments was calculated by adding the yield gained and the yield obtained from saved water (Equation 10; Hassene & Seid, 2017)

\[
\frac{\text{YI}}{\text{D}} = \frac{(\text{YF} - \text{YD}) \times 100}{\text{YF}} \quad (10)
\]

where \(\text{YI}\) = Yield increment or decrement (%), \(\text{YF}\) = Yield from full irrigation (Kg/ha), and \(\text{YD}\) = Yield from deficit level Kg/ha.

### 3.5. Statistical analysis

The statistical difference of crop phenology and yield attributes were analyzed using MSTAT-C statistical package for analysis of variance. Wherever notable treatment effects were established, treatment means were compared using the Least Significant Difference (LSD) method.

### 4. Results and discussion

#### 4.1. Soil properties of the experimental field

The soil and irrigation water characteristics of the experimental field are presented in Table 2. Clay soil is the dominant soil texture throughout the experimental field. The average FC, PWP, and AW are 37.26%, 20.23%, and 165.00 mm/m, respectively. The average % of clay, silt, and sand are also 44.76, 37.67, and 17.57%, respectively.

The soil chemical analysis revealed that the average pH value of the soil ranged between 7.32 and 7.50. As a result, onion can grow outstanding in this soil condition and the finding is in line with Olani and Fikre, which concludes that the pH range of onion is between 6.0 and 8.0. The pH of irrigation water is not a problem by itself, but it is an indicator of other problems such as sodium and carbonates. According to Abdel-Fattah et al. (2020), the irrigation water is classified in terms of pH<7 low, 7–8 moderate, and >8 severe. Based on this classification, the pH value (7.46) of the irrigation water in the study area was found to be slight to moderate.

| **Table 2. Soil and irrigation water properties of the experimental field** |
|---|---|---|---|---|---|---|---|
| **Soil physical properties** |
| Depth (cm) | FC (%) | PWP (%) | AW (mm/m) | Clay (%) | Silt (%) | Sand (%) | Textural class (USDA) |
| 0–20 | 39.3 | 21.3 | 180 | 46.16 | 40.59 | 13.25 | Clay |
| 20–40 | 37.8 | 19.7 | 150 | 44.15 | 36.74 | 19.11 | Clay |
| 40–60 | 34.68 | 19.7 | 149.8 | 43.98 | 35.67 | 20.35 | Clay |
| Average | 37.26 | 20.23 | 165 | 44.76 | 37.67 | 17.57 | Clay |
| **Irrigation water qualities** |
| Depth (cm) | pH | EC (ds/m) | OM (%) | OC (%) | pH | EC (ds/m) |
| 0–20 | 7.32 | 0.45 | 5.63 | 2.49 | 7.46 | 0.274 |
| 20–40 | 7.50 | 0.45 | 5.24 | 2.26 | 7.52 | 0.283 |
| 40–60 | 7.51 | 0.46 | 5.22 | 2.21 | 7.63 | 0.282 |
| Average | 7.44 | 0.45 | 5.36 | 2.32 | 7.54 | 0.28 |

N.B: FC = Field capacity, PWP = Permanent wilting point, and AW = Available water
According to Corwin and Lesch (2005), water salinity has four classes: C1, C2, C3, and C4, with low, medium, high, and very high salinity levels of 0.1–0.25 dS/m, 0.25–0.75 dS/m, 0.75–2.25 dS/m and >2.25 dS/m, respectively. The average electrical conductivity of the experimental field was 0.262 dS/m for a soil profile of 40 cm which was below the threshold value for onion, i.e. 1.2 dS/m. The soil of the experimental field was classified under medium salinity. The organic matter and organic content of the soil were 5.68% and 3.3%, respectively.

5. Irrigation scheduling

5.1. Climate

The data revealed that the maximum temperature ranged between 27.71°C—30.96°C and the minimum temperature ranged from 14.66°C—19.18.85°C during the crop growth period. The reference evapotranspiration ranged from 3.63 to 4.40 mm/day (Table 3).

The variation of rainfall and effective rain are shown in Table 4. The mean maximum rainfall was recorded at the end of September and beginning of October during the initial stage of the growth period and the mean minimum rainfall was recorded during January at the late crop growth stage.

The water applied at each deficit level is presented in Figure 3.

The depths of irrigation at each treatment were different, based on the percent it required. At the initial stage, all the treatments received the same depth of water (Table 5).

### Table 3. Climatic data used at the study period

| Months    | Temperature (°C) | Relative humidity (%) | Wind speed (m/sec) | Sun shine (hrs.) | Radiation (MJ/m²/day) | ETo (mm/day) |
|-----------|------------------|-----------------------|-------------------|-----------------|-----------------------|--------------|
|           | Minimum          | Maximum               |                   |                 |                       |              |
| August    | 18.85            | 29.39                 | 69.30             | 1.02            | 7.88                  | 21.60        | 4.10        |
| September | 18.05            | 27.71                 | 60.60             | 0.31            | 6.67                  | 22.50        | 3.63        |
| October   | 17.97            | 28.13                 | 61.89             | 0.55            | 7.59                  | 22.40        | 3.82        |
| November  | 16.70            | 29.75                 | 50.49             | 0.08            | 8.84                  | 21.00        | 3.91        |
| December  | 14.66            | 30.96                 | 64.44             | 0.03            | 9.98                  | 20.90        | 4.40        |
| January   | 17.18            | 30.84                 | 44.24             | 0.00            | 9.12                  | 18.20        | 4.09        |
| Average   | 17.24            | 29.46                 | 58.49             | 0.33            | 8.35                  | 21.10        | 4.18        |

### Table 4. Total rainfall and effective rainfall

| Irrigation date | 6-Oct | 10-Oct | 17-Oct | 26-Oct | 5-Nov | 12-Nov | 16-Nov | 20-Nov | 24-Nov | 1-Dec |
|-----------------|-------|--------|--------|--------|-------|--------|--------|--------|--------|-------|
| Total Rf        | 2.57  | 6.67   | 8.61   | 18.64  | 12.54 | 0.6    | 0      | 0      | 18.72  | 2.44  |
| Effective Rf    | 2.54  | 6.70   | 8.57   | 18.60  | 12.50 | 0.6    | 0      | 0      | 18.70  | 2.40  |
| Irrigation date | 9-Dec | 13-Dec | 17-Dec | 21-Dec | 25-Dec| 29-Dec | 2-Jan  | 5-Jan  | Total  |
| Total Rf        | 0     | 0      | 0      | 0      | 0     | 0      | 0      | 0      | 85.73  |
| Effective Rf    | 0     | 0      | 0      | 0      | 0     | 0      | 0      | 0      | 83.13  |
| Irrigation interval at each stage (days) | 3 |
The irrigation interval at initial, development, bulb formation, and late growth stage are 4, 6, 4, and 3 days. The overall irrigation interval of onion crop was 3 days (Table 6). Applying deficit irrigation below 3 days gave maximum yield, whereas, the yield decreases, when applying irrigation above 3 days. This result was in line with Ayza (2018). The irrigation interval increases, the yield output decreases (Wale & Girmay, 2019). Therefore, finding an optimum irrigation interval gives high yield (Lendabo et al., 2021).

5.2. Applied water in various treatments

The seasonal net depths of irrigation, crop water requirements, and gross depth of irrigation at each growth stage for the crop season for different treatments are presented in Table 7. The net depth of irrigation, effective rainfall, and the gross depth of irrigation were 311.80, 83.10 mm, and 445.42 mm. These result approximates with the finding of Nurga et al. (2020; Dirirsa et al. (2017). The minimum net, CWR, and gross irrigation were recorded at 235.75, 318.85 and 364.57 mm at applying 25%IR at bulb formation stage.

5.3. Deficit irrigation effects on crop phenology and yield

The crop phenology and yield attributes were significantly different (Fcal>Fprob). The ANOVA result revealed that the crop height measured at the end of the crop season had a highly remarkable (P < 0.01) difference among treatments. The highest crop height (56.85 cm) obtained from applied full irrigation throughout the crop season has no substantial different with the applications of 75%IR during development, bulb formation and late-season stages and 50%IR applications during development and late-season stages. The crop height was obtained from applied 50%IR at bulb formation stage and 25%IR at late growth stage. The shortest crop height was measured 49.91 cm from received 25%IR at bulb formation stage had no major difference with 25%IR in development and late-season. It was the same as received 50%IR in bulb formation stage stages (Table 8).

The results indicated that crop height of onion decreased as soil moisture level decreased from 100%IR to low soil moisture level of 25%IR. This indicates that the plant height of the onion that received maximum applied water was higher than the onion that received the minimum amount of water applied. In addition, applying irrigation level of 50%IR at the bulb formation stage and applying irrigation level of 25%IR at a late stage significantly the same. The maximum crop phenology obtained from the application of full irrigation and the minimum were obtained from high deficit irrigation level. The leaf length of onion was (p < 0.05) affected by the level of irrigation. The highest leaf length of 49.79 cm was obtained from the applied full irrigation had no major difference with 75%IR applications during development, bulb formation and late-season stages. The leaf length obtained from the application of 75%IR at development and late growth stages were significantly the same. The leaf length obtained for the applications of 50%IR at any growth stage were also significantly the same as the leaf length obtained from the applications of 25%IR.
| Growth stage          | Irrigation dates | T1 (control) | % IR | T2 | T3 | T4 | T5 | T6 | T7 | T8 | T9 | T10 |
|----------------------|------------------|--------------|------|----|----|----|----|----|----|----|----|-----|
| **Initial stage**    |                  |              |      |    |    |    |    |    |    |    |    |     |
| 28-Sep               | 11.43            | 11.43        | 11.43|    |    |    |    |    |    |    |    |     |
| 6-Oct                | 20.00            | 20.00        | 20.00|    |    |    |    |    |    |    |    |     |
| 10-Oct               | 19.00            | 19.00        | 19.00|    |    |    |    |    |    |    |    |     |
| **Development stage**|                  |              |      |    |    |    |    |    |    |    |    |     |
| 17-Oct               | 18.14            | 13.61        | 18.14|    |    |    |    |    |    |    |    |     |
| 26-Oct               | 29.86            | 22.39        | 29.86|    |    |    |    |    |    |    |    |     |
| 5-Nov                | 20.57            | 15.43        | 20.57|    |    |    |    |    |    |    |    |     |
| 12-Nov               | 27.14            | 20.36        | 27.14|    |    |    |    |    |    |    |    |     |
| 16-Nov               | 21.14            | 15.86        | 21.14|    |    |    |    |    |    |    |    |     |
| **Bulb formation stage** |            |              |      |    |    |    |    |    |    |    |    |     |
| 20-Nov               | 23.14            | 23.14        | 17.36|    |    |    |    |    |    |    |    |     |
| 24-Nov               | 18.86            | 18.86        | 14.14|    |    |    |    |    |    |    |    |     |
| 1-Dec                | 18.14            | 18.14        | 13.61|    |    |    |    |    |    |    |    |     |
| 5-Dec                | 28.57            | 28.57        | 21.43|    |    |    |    |    |    |    |    |     |
| 9-Dec                | 28.29            | 28.29        | 21.21|    |    |    |    |    |    |    |    |     |
| 13-Dec               | 27.86            | 27.86        | 20.89|    |    |    |    |    |    |    |    |     |
| **Late stage**       |                  |              |      |    |    |    |    |    |    |    |    |     |
| 17-Dec               | 26.57            | 26.57        | 26.57|    |    |    |    |    |    |    |    |     |
| 21-Dec               | 22.57            | 22.57        | 22.57|    |    |    |    |    |    |    |    |     |
| 25-Dec               | 24.57            | 24.57        | 24.57|    |    |    |    |    |    |    |    |     |
| 29-Dec               | 22.00            | 22.00        | 22.00|    |    |    |    |    |    |    |    |     |
| 2-Jan                | 21.14            | 21.14        | 21.14|    |    |    |    |    |    |    |    |     |
| 5-Jan                | 16.43            | 16.43        | 16.43|    |    |    |    |    |    |    |    |     |
| **Total**            | 445.43           | 416.2        | 409.2| 412.1| 387| 373| 378.8| 357.8| 336.8| 345.5|
Table 6. Irrigation interval and depth of irrigation water applied

| Growth stages | Initial | Development |
|---------------|---------|-------------|
| Irrigation days | 28-Sep 6-Oct 10-Oct | 17-Oct 26-Oct 5-Nov 12-Nov 16-Nov |
| Depth of Water (mm) | 11.43 20.00 19.00 | 18.14 29.86 20.57 27.14 21.14 |
| Irrigation interval (days) | - 8 4 | 7 9 9 7 6 |
| Irrigation interval at each stage | 4 | 6 |

| Growth stages | Bulb formation |
|---------------|-------------|
| Irrigation days | 20-Nov 24-Nov 1-Dec | 5-Dec 9-Dec 13-Dec |
| Depth of Water (mm) | 23.14 18.86 18.14 | 28.57 28.29 27.86 |
| Irrigation interval (days) | 4 4 5 | 4 4 4 |
| Irrigation interval at each stage | | 4 |

| Growth stages | Late |
|---------------|-----|
| Irrigation days | 17-Dec 21-Dec 25-Dec | 29-Dec 2-Jan 5-Jan |
| Depth of Water (mm) | 26.57 22.57 24.57 | 22.00 21.14 16.43 |
| Irrigation interval (days) | 4 4 4 | 4 3 3 |

at late growth stage. The minimum leaf length of 42.86 cm was obtained from 25%IR application during bulb formation stage and shows no specific difference with the applied 25%IR during development stage. The number of leaf obtained were significantly the same at any deficit irrigation level. The bulb diameter obtained from the application of 75%IR at bulb formation stage was not significantly different from the application of 50% IR at development and late growth stage (Halimeh & Amir, 2020). At the same principle, the bulb diameter obtained at development and late growth stage were significantly the same at the same deficit level. The maximum yield (25.88 ton/ha) obtained from the application of full irrigation was significantly with the application of 75%IR at late growth stage. The minimum yield (18.01 ton/ha) obtained from the application of 25%IR at bulb formation stage. The remained treatments were significantly different. Generally, the crop phenology and yield attributes obtained were decrease from the application of full to 25%IR. These result also fitted with the finding of Ashemi (2021). These finding also in line with the result obtained by Mila et al. (2017); Tolossa and Yildiz (2021). The amount of irrigation water provided had a strong correlation with crop height and leaf length.

At the end of the growth stage, the highest leaf length was observed from applying deficit irrigation at the late stage followed by development and bulb formation stage with the same deficit level but in a different growth stage. Leaf length is reduced when the moisture stress occurs at development (vegetative) and bulb formation (flowering) stages (Meskelu et al., 2014; Admasu et al., 2019). The decreasing order of sensitivity stages of onion crop were bulb formation stage, development and late growth stage respectively. This finding was similar with result obtained by Ntukamazina et al. (2017).

The highest number of leaves (9.42) per plant obtained from the applied of full irrigation (T1) and the minimum plant height (8.18) was recorded from treatment T9 (received 25%IR at bulb formation stage). The results show that irrigation application level has a direct effect on vegetative growth. This indicated that as irrigation application-level decreased from non-stress (T1) to high-stress level (T10), the number of leaves decreased (Nurgo et al., 2020). It has also been assessed that the higher irrigation water depth applied produced higher vegetative parameters (Birhanu & Zeleke, 2010; Nagaz et al., 2012; Tolossa & Yildiz, 2021).
The correlation coefficients of crop height, leaf length, and number of leaf were 0.8685, 0.8626, and 0.8717, respectively. The same for bulb height, bulb diameter, and yield were 0.8295, 0.8001, and 0.8612, respectively. These values showed that, the applied water directly related with the crop phenology and yield attributes (Figure 4).

5.4. Optimum deficit irrigation level
The yield increments or decrements are expressed in Table 9. The maximum marketable yield was 25.88 ton/ha obtained at the control treatment (100%IR) followed by 25.70 ton/ha from applying 75%IR at late growth stage. The minimum yield was 18.01 ton/ha obtained from applied 25%IR at bulb formation stage. The maximum irrigation water saved (760.50 m³/ha) from the application of 25%IR at bulb formation stage. The minimum irrigation water saved (204.50 m³/ha) from the

| Treatment | Initial (mm) | Development (mm) | Mid (mm) | Late (mm) |
|-----------|--------------|------------------|---------|----------|
| T1        | 35.30        | 81.80            | 101.40  | 93.30    |
| T2        | 35.30        | 61.35            | 101.40  | 93.30    |
| T3        | 35.30        | 81.80            | 76.05   | 93.30    |
| T4        | 35.30        | 81.80            | 101.40  | 69.98    |
| T5        | 35.30        | 40.90            | 101.40  | 93.30    |
| T6        | 35.30        | 81.80            | 50.70   | 93.30    |
| T7        | 35.30        | 81.80            | 101.40  | 46.65    |
| T8        | 35.30        | 20.45            | 101.40  | 93.30    |
| T9        | 35.30        | 81.80            | 25.35   | 93.30    |
| T10       | 35.30        | 81.80            | 101.40  | 23.33    |

Table 7. Amount of net irrigation applied at each growth stage

| Treatment | CH (cm) | LL (cm) | NO. of leaves | BD (cm) | BH (cm) | Yield (ton/ha) |
|-----------|---------|---------|---------------|---------|---------|----------------|
| T1        | 445.42  | 56.85   | 49.79         | 9.42    | 6.56    | 6.45           |
| T2        | 445.93  | 55.93   | 49.51         | 9.16    | 5.63    | 5.40           |
| T3        | 439.43  | 55.04   | 48.00         | 9.11    | 5.43    | 5.20           |
| T4        | 443.50  | 56.84   | 49.78         | 9.41    | 6.46    | 6.35           |
| T5        | 415.00  | 54.70   | 46.12         | 8.91    | 5.20    | 5.03           |
| T6        | 402.00  | 53.01   | 45.96         | 8.81    | 4.96    | 4.79           |
| T7        | 410.14  | 55.03   | 47.98         | 9.09    | 5.42    | 5.25           |
| T8        | 384.07  | 51.53   | 44.84         | 8.70    | 4.46    | 4.28           |
| T9        | 364.57  | 49.91   | 42.86         | 8.18    | 3.98    | 3.80           |
| T10       | 376.79  | 53.02   | 45.95         | 8.8     | 4.65    | 4.43           |
| Fcal      | 2.489   | 4.03    | 0.736         | 0.836   | 0.863   | 1.05           |
| Fprob     | 0.111   | 0.036   | 0.493         | 0.439   | 0.439   | 0.37           |
| CV (%)    | 3.5     | 2.2     | 13.2          | 9.9     | 10.2    | 1.39           |
| LSD       | 3.3     | 1.8     | NS            | 1.5     | 0.9     | 0.55           |

Table 8. Effects of deficit irrigation on onion crop physiology and yield attributes

N.B: The same letter in columns are not significantly different at P ≤ 0.05, CV = coefficient of variation, and LSD = Least Significant Difference. CH = Crop height, LL = Leaf length, BD = Bulb diameter, and BH = Bulb height.
application of 75%IR at development stage. The extra yields obtained from saved water were ranged from 1.75 to 6.08 ton/ha. Generally, the yield decreases as the applied water decreases. The present finding was similar with the result obtained, (Amare & Abebe, 2020; Parkash et al., 2021). The maximum yield increment recorded was 1.82 ton/ha (50%IR at late stage) followed by 1.54 ton/ha (25%IR at late growth). The YI and IWUEI were negative at 25%IR both at bulb formation and development stage. However, the YI and IWUEI were positive at the remaining treatments. The positive YI and IWUEI showed that, there were extra yield from the full irrigation. The negative YI and IWUEI showed no yield increment. The YI and IWUEI were positive for applying irrigation water above 50%IR at any growth stages. However, the increment was negative applying irrigation water below 25%IR at any growth stage except at late growth stage. Generally, applying deficit irrigation above 50%IR at any growth stages gained extra yield.

5.5. Correlation between crop phenology with yield
The crop phenology had a strong correlation with the yield (Table 10). The correlation indicated that onion crop height, leaf length, leaf number are directly related to the yield. Finally, the trial analysis was performed considering yield as the main dependent variable. The application of irrigation water had a direct relation to growth parameters and yield components of the crop. The Pearson's correlation coefficient of crop height, leaf length, and number of leaf are 0.99, 0.98, and 0.99, respectively. The value indicates that they are strongly correlated. This indicated that
plant height and bulb diameter had a positive correlation with bulb yield, bulb diameter and bulb height (De Oliveira et al., 2020; Trivedi & Dhimal, 2010).

5.6. Economic comparison of stage specific moisture stress
The detailed economic returns of each irrigation level are given in Table 11. The effect of deficit irrigation level also affects economic productivity. Consideration the Ethiopian currency (Birr), the highest net benefit and benefit–cost ratio were found from application of 100%IR as 175,621 Birr/ha and 2.19, respectively, while the lowest net benefit and benefit–cost ratio were 80,356 Birr/ha and 1.55, respectively, obtained from treatment T9, which was lower bulb yield followed by treatment T8 which had the same amount of deficit level apply except stage (i.e. application of irrigation water by 25%IR at late and development stage of crop growth respectively). Stressing at 75% gives less economic return than stressing 50% and 25%. Moreover, the cost–benefit ratio and net return of the treatments in increasing order based on growth stage were mid-stage, development stage, and late growth stage. The maximum economic irrigation water productivity was observed in T7, T10, and T4.

6. Conclusions
The crop production in Ethiopia does not comply with the growing population due to water scarcity. With the aim of using the available water, alternate options are developed. An experimental mode was executed to determine the optimum irrigation scheduling and optimum deficit irrigation level of onion crop. The experiment was designed as ten-treatment combinations replicated three times under Random Complete Block Design. The treatments were developed with three deficit irrigation levels (75%IR, 50%IR, and 25%IR) at four growth stages. For a broad

| Treatments | Y (ton/ha) | IWUE (Kg/m³) | WS (m³/ha) | EYSW (ton/ha) | ELSW (ha) | YI (ton/ha) | IWUEI (%) |
|------------|------------|---------------|-------------|---------------|-----------|-------------|------------|
| T1         | 25.88      | 5.81          | -           | -             | -         | -           | -          |
| T2         | 25.00      | 6.01          | 204.50      | 1.75          | 0.07      | 0.86        | 3.4        |
| T3         | 24.34      | 6.00          | 253.50      | 2.17          | 0.09      | 0.85        | 2.38       |
| T4         | 25.70      | 6.15          | 233.25      | 2.05          | 0.08      | 1.54        | 7.35       |
| T5         | 23.00      | 6.04          | 409.00      | 3.53          | 0.15      | 1.01        | 2.31       |
| T6         | 22.00      | 6.05          | 507.00      | 4.38          | 0.19      | 1.05        | 1.53       |
| T7         | 24.30      | 6.12          | 466.50      | 4.15          | 0.18      | 1.82        | 10.44      |
| T8         | 20.53      | 5.74          | 613.50      | 5.03          | 0.24      | -0.34       | -1.25      |
| T9         | 18.01      | 5.34          | 760.50      | 5.81          | 0.32      | -2.08       | -7.99      |
| T10        | 21.9       | 6.08          | 699.75      | 6.08          | 0.29      | 1.20        | 9.13       |

N.B: T10 = Yield, IWUE = Irrigation Water Use Efficiency, WS = Water Saved, EYSW = Extra Yield from Saved Water, ELSW = Extra Land from Saved Water, YI = Yield Increment, IWUEI = Irrigation Water Use Efficiency Increment.

Table 10. Pearson’s correlation coefficient (r)

|       | CH  | LL  | NL  | BD  | BH  | MY  |
|-------|-----|-----|-----|-----|-----|-----|
| CH    | 1   |     |     |     |     |     |
| LL    | 0.97| 1   |     |     |     |     |
| NL    | 0.97| 0.97| 1   |     |     |     |
| BD    | 0.96| 0.95| 0.96| 1   |     |     |
| BH    | 0.95| 0.94| 0.95| 1   | 1   |     |
| MY    | 0.99| 0.98| 0.99| 0.95| 0.94| 1   |

N.B: CH = Crop Height, LL = Leaf Length, NL = Leaf Length, BD = Bulb Diameter, BH = Bulb Height, MY = Marketable Yield.
### Table 11. Economic comparison of benefit to cost ratio

| Indicators                              | T1       | T2       | T3       | T4       | T5       | T6       | T7       | T8       | T9       | T10      |
|-----------------------------------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| Gross benefit (Birr/ha)                 |          |          |          |          |          |          |          |          |          |          |
| From Onion yield                        | 323,625  | 312,500  | 307,031  | 317,188  | 292,188  | 282,031  | 294,531  | 256,563  | 225,000  | 262,625  |
| From Saved water                        | 0        | 0.61     | 0.76     | 0.7      | 1.23     | 1.52     | 1.4      | 1.84     | 2.28     | 2.1      |
| From Saved time                         | 0        | 451      | 559      | 514      | 902      | 1118     | 1028     | 1352     | 1677     | 1543     |
| From Total profit                       | 323,625  | 312,952  | 307,591  | 317,702  | 293,090  | 283,151  | 295,561  | 257,917  | 226,679  | 264,170  |
| Variable costs (Birr/ha)                |          |          |          |          |          |          |          |          |          |          |
| For labor Cost for irrigation           | 6873.92  | 6422.99  | 6334.97  | 6359.72  | 5972.22  | 5756.17  | 5845.52  | 5521.45  | 5197.38  | 5331.17  |
| For cost of irrigation water            | 13.44    | 12.53    | 12.05    | 12.4     | 11.61    | 10.65    | 11.35    | 10.69    | 9.26     | 10.3     |
| For seed cost                           | 3200     | 3200     | 3200     | 3200     | 3200     | 3200     | 3200     | 3200     | 3200     | 3200     |
| For transplanting                       | 8333     | 8333     | 8333     | 8333     | 8333     | 8333     | 8333     | 8333     | 8333     | 8333     |
| For harvesting                          | 20,833   | 20,833   | 20,833   | 20,833   | 20,833   | 20,833   | 20,833   | 20,833   | 20,833   | 20,833   |
| For weeding                             | 50,000   | 50,000   | 50,000   | 50,000   | 50,000   | 50,000   | 50,000   | 50,000   | 50,000   | 50,000   |
| For land preparation                    | 58,750   | 58,750   | 58,750   | 58,750   | 58,750   | 58,750   | 58,750   | 58,750   | 58,750   | 58,750   |
| Total cost                              | 148,004  | 147,552  | 147,444  | 147,489  | 147,100  | 146,833  | 146,974  | 146,649  | 146,323  | 146,458  |
| MRR                                     | 175621   | 165,399  | 160,147  | 169,213  | 145,990  | 136,267  | 148,588  | 111,268  | 80,356   | 117,712  |
| B/C                                     | 2.19     | 2.12     | 2.09     | 2.15     | 1.99     | 1.93     | 2.01     | 1.76     | 1.55     | 1.8      |

**N.B:** All parameters are in units of Birr/ha, MRR = Marginal Rate of Return, and B/C = Benefit to Cost Ratio
understanding, the effects of these treatments, control plots with 100%IR (full irrigation) were considered. The amount of water applied was monitored using calibrated outlet. To achieve a high production potential of onion, appropriate soil moisture was maintained during the entire growing season. The irrigation intervals at growth stages were 4, 6, 4, and 3 days, respectively, with an overall irrigation interval of 3 days. The highest crop phenology and yield were obtained from 100%IR and the lowest from applied 25%IR. It was inferred that the application of above 50%IR at 3 days interval was economically productive at water scarce area. Applying below 25%IR at 3 days interval at any growth stages except late growth stages didn’t gave extra yield. Therefore, applying deficit irrigation level above 50%IR gives extra yield, whereas, applying deficit irrigation above 25% was not optimal. Therefore, applying deficit irrigation above 50%IR gave extra yield rather than applying full irrigation. However, applying deficit irrigation above 25% is never recommended. The method adopted in this research provides an economically feasible structure and the saved water can be used to cultivate more land. This technique is suitable for successful utilization of limited water for increasing crop production especially in arid and semi-arid regions.

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Author details
Babar Tesfaye Yersaw1
Tarun Kumar Lohani1
E-mail: tarun.kumar@amu.edu.et
ORCID ID: http://orcid.org/0000-0003-4804-9711
1 Department of Water Resources and Irrigation Engineering, Arba Minch University, Arba Minch, Ethiopia.
2 Department of Hydraulic and Water Resources Engineering, Arba Minch University, Arba Minch, Ethiopia.

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