Onion yield response to irrigation level during low and high sensitive growth stages and bulb quality under semi-arid climate conditions of Western Ethiopia

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Abstract: Under the scarcity of irrigation water, the need to use the available water economically and efficiently is unquestionable. Deficit irrigation improves water use efficiency, by maintaining soil moisture content below optimum level throughout the growing season. The objective of this study was to study the effect of onion yield response to irrigation level during low and high sensitive growth stages and bulb quality under semi-arid climate conditions. The treatments consisted of 10 different levels of irrigation water application. The experiments were laid out in RCBD with three replications. The result showed that the variation in the level of irrigation water application had a significant effect on onion yield. Treatments that had deficit irrigation and skipping of irrigation in one growth stage had a lower yield than those that had full irrigation (P < 0.05). The highest total onion yield was observed from a control treatment (full irrigation), which was not statically different from the treatment receiving 75% ETc and no irrigation at the initial and late-season stage. Deficit by 75% ETc throughout the growing season resulted in the highest yield reduction. The crop water use efficiency was the lowest under full irrigation and the highest under 75% deficit throughout the growing stages. From resource conservation point of view, maximum water use efficiency may be of interest, which could be obtained under severe deficit irrigation. Therefore, there is a need to find out the deficit level at which a reasonable level of water saving can be achieved without significant yield loss, which could be of significant importance for both production and water conservation.

ABOUT THE AUTHOR

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PUBLIC INTEREST STATEMENT

The use of water for agricultural production in water scarcity regions requires innovative and sustainable research. The present water shortage is one of the primary world issues, and according to climate change projection, it will be more critical in the future. Since water availability and accessibility are the most significant constraining factors for crop production, addressing this issue water use efficiency may be of interest, which could be obtained under deficit irrigation.
Subjects: Agriculture & Environmental Sciences; Soil Sciences; Agronomy; Aquaculture

Keywords: onion crop; water use efficiency; irrigation level; growth stages; onion yield

1. Introduction
In Ethiopia, the planted area for onions was 22,036 ha and the production of onions was estimated to be 236,922 tons (CSA, 2007). According to CSA (2007) the private farmers’ holdings in “Meher” season 2012/2013, the total area coverage of the onion crop in the country was 21,865.4ha, with a total production of 219,188.6 tons with an average productivity of 10.02 tons/ha. During the 2013/2014 cropping season, the total area under onion production was estimated to be 24, 375.7 ha with an average yield of about 9.02 tons/ha and estimated total production of greater than 219,735.27 tons (CSA, 2007). This is a very low yield as compared to the world average of 19.7 tons/ha.

Onion (Allium cepa L.) is considered as one of the most important and major irrigated vegetable crops produced on a large scale in Ethiopia. It is usually cultivated in the dry season from September to March in which there is typically little precipitation (Food and Agricultural Organization [FAO], 2012). It is very responsive to the amount of irrigation water applied: good bulb yield when irrigation is sufficient and low bulb yield when not (Gebregewgiris et al., 2016).

Water is becoming scarce, not only in arid and drought-prone areas but also in regions where rainfall is abundant (Pereira et al., 2002). In areas where water is the most limiting resource to production, maximizing water productivity may be more profitable to the farmer than maximizing crop yield. This is because the water saved when deficit irrigation is applied becomes available to irrigate more land since the latter is not a limiting factor. Deficit irrigation is needed where essential resources such as water, capital, energy, and labor are limited. Under deficit irrigation, crops are deliberately allowed to sustain some water deficit and yield reduction. The irrigator aims to increase water use efficiency (WUE) by reducing the amount of water at irrigation or by reducing the number of irrigation (Anbese et al., 2020; Nikolaou et al., 2020). The growth and yield of any crop are related to the amount of water used. The variable amount of water contained in soil, and its energy state is important factors affecting the growth of plants (Hillel, 2004).

In many developing countries like Ethiopia, water application intervals are mutually agreed upon and fixed among growers (FAO, 2016). However, this method does not consider how and when to apply. In the Ambo area, irrigation is applied on a routine basis, inadequate management of irrigation water and absence of scheduling has been an important limiting factor to the onion and other crop production (Ambo Agricultural Research Center [AARC], 2017). The farmers generally lack knowledge on aspects of soil-water-plant relationships; they apply water to crop regardless of plant needs. Therefore, knowledge of irrigation application is when to irrigate, how much water to apply, and what level of stress at different growth stages is essential to optimize crop production per unit water.

Ambo Agricultural Research Center is located in the highland of the country and has focussed primarily on maximizing total production, but in recent years; the focus has shifted to limiting factors in the production system, notably the availability of either land or water. Within this context, deficit irrigation has been widely investigated as a valuable strategy during dry seasons when rainfall is the limiting factor in crop cultivation (AARC, 2017). The general objective of this study was, therefore, to evaluate Onion Yield Response to Irrigation Level during Low and High Sensitive Growth Stages and bulb quality under Semi-Arid Climate Conditions of Western Ethiopia.

2. Materials and methods

2.1. Description of the study area
The experiment was carried at Ambo agricultural Research Center, Western Oromia. The Research Center is located at about 115 km west of Addis Ababa, at an altitude of 2225 m. It is located at 08°57”N latitude and 37°52”E longitude. The area has a warm humid climate with the mean
monthly minimum, maximum temperatures, and an average total annual rainfall of about 10.3°C, 26.4°C, and 1036 mm, respectively.

The soil type of the area is clay with sand, silt, and clay in a proportion of 15%, 17%, and 68%, respectively (AARC, 2017). Major crop cultivation includes high land maize (Zea mays L.), teff (Eragrostis tef), common bean (Phasaleus vulgaris), potato (Solanum tuberosum L.), onion (Allium cepa L.), and tomato (Solanum lycopersicum). Four seasons established data based on weather and climatic conditions of the area were used to define the seasons as the dry season (December to February), spring (March to May), summer (June to August), and autumn (September to November). Farmers grow crops twice a year, once during the dry season (December to February); by using Huluka and Taltale River that flows close to the area and regularly summer season, they use rainfall.

2.2. Climatological data
Twenty years of climatic data (Table 1) on monthly basis was collected from the Ethiopian Meteorological Agency. The mean daily ETo was calculated by the CROPWAT model. The CROPWAT program using a USDA method for the monthly total rainfalls computed the effective rainfall. Depending on the rainfall coefficient, the seasons of the study area were classified into three, dry season, small rain season, and big rain season. During the dry season the farm activity depends on full irrigation, while in the small rainy season using rainfall alone is not enough for crop production, so supplementary irrigation is required.

2.3. Experimental design, procedures and cultural practices
The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications (Figure 1). The experiment consisted of 10 treatments with varying levels of irrigation water throughout the growing season.

The experimental field was ploughed using a tractor, levelled, and made ready for planting. The plot size was 1.5 * 3 m = 4.5 m² area. The distance between blocks, plots, rows, and plants was 3 m, 1.5 m, 0.30 m, and 0.10 m, respectively. The furrow consisted of five rows in each plot and 30 plants in each row, the plot was designed with four furrows and three ridges.

2.4. Site selection and soil sampling
Three representative composite soil samples were collected randomly from each block at 0–20 cm, 20–40 cm, and 30–60 cm soil depths before and after irrigation using an auger. The soil subsamples were mixed thoroughly, dried at room temperature, ground, and sieved through a 2 mm screen for physicochemical analysis; whereas for OC and total N determination, soil samples were passed through a 0.5 mm sieve.

The size distribution of the soil (2 mm sieve and 0.5 mm sieve), physical analysis was depending on the US Department of Agriculture (USDA) standard. Soil samples were also collected from six locations of the experimental area at 0–20 cm, 20–40 cm, and 30–60 cm depths for determination of field capacity (FC), permanent wilting point (PWP), total available water (TAW) and bulk density.

2.4.1. Soil bulk density
Soil bulk density is defined as the oven-dry weight of soil in a given volume, as it occurs in the field. It was determined by the core method. The undisturbed soil sample was collected from the field at three depths 0–20 cm, 20–40 cm, and 40–60 cm oven-dried for 24 h at 105°C and weighed for determination of dry weight using the following formula:

$$PB = \frac{Wd}{VC}$$

(1)
2.4.2. Soil texture
Disturbed soil samples were collected from a representative location of the field and the textural class was determined by using the pipette method in the laboratory.

2.4.3. Soil moisture content
The soil moisture content at field capacity (FC) and permanent wilting point (PWP) was determined soil sample collected from 0 cm to 20 cm, 20–40 cm, and 40–60 cm soil depth by considering effective root zone of the onion, collected three-sample depths at the experimental area. The soil sample was sun-dried and crushed then, soaked in water for 1 day (24 h) pressure plate apparatus, and pressure membrane apparatus were used for the determination of moisture content at FC and PWP. A suction of −one-third bar and −15 bar was exerted for FC and PWP, respectively, for the determination of soil moisture content of the soil. After getting the moisture content of soil on a weight basis corresponding to these constants, soil moisture content on a volume basis was determined by multiplying it by soil bulk density.

2.4.4. Total available water
Plant use in root zone computed as the difference in moisture content between FC and PWP using the following expression.

\[ TAW = 100 \sum (\theta_{FC} - \theta_{PWP})Zr \]  

(2)

2.4.5. Soil moisture determination
Soil samples were collected before and after irrigation events from the experimental plots at 0–20 cm, 20–40 cm, and 40–60 cm depths with in effective root considering the wetting front of irrigation using an auger to determine the moisture content by considering onion root zone in each growth stage. The collected samples from each plot were weighed and placed in a drying oven for 24 h at a temperature of 105°C. The soil samples were weighed again. The gravimetric water content was obtained (Equation (3)), converted to volumetric water content by multiplying with the soil bulk density and root depth of onion to get available field/current moisture at the time of irrigation.
\[ \vartheta_{dw} = \frac{W_w - W_d}{W_d - W_c} \times 100 \] (3)

2.4.6. Soil organic matter content
Soil organic matter content was calculated by multiplying the percent OC by 1.724. Organic Carbon (C) was determined using the Walkley & Black method (Nelson & Sommers, 1996).

2.4.7. Soil pH measurement
The pH of the soil was measured potentiometrically in the supernatant suspension of 1:1.5, soil:water mixture.

2.4.8. Electrical conductivity (EC)
Sample from the study area was determined by measuring the conductivity of saturated soil extract using an Electrical conductivity meter.

2.5. Irrigation water application
The values of ETo estimated using the CROPWAT model based on climatological parameters need to be adjusted for the actual crop. Water applied for plots throughout the growing season is applied by 100% ETc and 25% ETc throughout the growing season and 75% ETc and 50% ETc in the growth stages of irrigation furrow systems was calculated.

The source of water used for the study was from Huluka River to the tank and was brought to the field under gravity using a closed pipe that runs adjacent to experimental plots. Water is then directed to smaller supply channels that feed the furrows. Through careful opening and closure of channel banks, the water was supplied into furrows up to their storage capacity. Water was carefully controlled to avoid the flow of water into water deficit plots. Water applications for full irrigation treatments were based on the estimated (mean) crop water requirement calculated over the entire growing season.

A 3-inch standard Parshall flume, manufactured in Ambo Agricultural Research Center by the mechanization research team was installed near the upstream of the experimental field to measure irrigation water applied to individual plots. An average discharge was diverted into the experimental field from a tertiary canal. This discharge was allowed to flow into one plot at a time. With the aid of a calculator and a stopwatch, the flow discharge into each plot and the time required to apply the desired depth of water was immediately calculated as soon as water was introduced into the plot. Water was allowed into the plot and each furrow for the time calculated. Immediately after the desired depth, applied plots were closed with the channel banks to stop water from entering the plots.
2.6. CROPWAT input data
Calculation of water and irrigation requirement utilizes input data on climate, crop, soil method of irrigation, and rainfall (Table 2). The climatic input data required are reference evapotranspiration and rainfall. Reference evapotranspiration was calculated from actual temperature, humidity, sunshine, and wind speed data according to the FAO Penman-Monteith method (Smith & Munoz, 2002). The crop parameters used for estimation of crop evapotranspiration, water balance calculation, and yield reduction due to stress include crop coefficient (kc), length of the growing season, critical depletion level (p), and yield response factor (ky). The program includes standard data for the main crop and it is possible to adjust them to meet actual conditions.

The effect of deficit irrigation on yield simulated by setting the dates and the application depth of water. Through moisture water content and evapotranspiration rate, the soil-water balance was calculated on a weekly basis by the CROPWAT model (Table 2).

2.6.1. Calculation procedure of the use of FAO CROPWAT model
Crop water requirement was determined by multiplying the ETo (Table 1) by the estimated kc value of onion for each growth stage (vegetative, development, mid-growing, and late-season). Through the estimate of the effective rainfall, irrigation requirement was calculated assuming the optimum water supply. With inputs on soil-water retention, infiltration characteristics, and rooting depth, the model calculated daily soil-water balance was calculated by the model. Water content in root-zone soil was predicted by means of the water balance equation, which takes into account incoming and outgoing flow of water.

A number of models has been developed for scheduling irrigations under-limited water supplies. Many models determine the optimal irrigation strategies using stochastic or probabilistic models of weather variables. However, in any season, the current weather variables can be significantly different from their probabilistic or stochastic estimates.

The effect of water stress on onion bulb yield was quantified by relating relative yield decrease to the relative evapotranspiration deficit through empirical-derived yield response factor (Ky) (Smith, 2011). Analysis of an intensive set of research information yielded value for Ky for 26 crops at various growth stages (Smith & Munoz, 2002). These enabled the degree of sensitivity to water to be taken into account in the estimate of yield reduction for various crops and growth stages based on soil moisture status.

| Table 2. Crop input data of Bombay red onion |
|---------------------------------------------|
| **Growth stage**               | **Initial** | **Development** | **Mid-growing** | **Late** | **Total** |
|----------------------------------|-------------|-----------------|-----------------|----------|----------|
| Crop coefficient                 | 0.70        | 0.88            | 1.05            | 0.85     |          |
| Rooting depth (m)                | 0.25        | 0.43            | 0.60            | 0.60     |          |
| Depletion level (fraction)       | 0.25        | 0.20            | 0.15            | 0.45     |          |
| Yield response factor            | 0.45        | 0.55            | 0.80            | 0.33     |          |
| Length of growing day            | 15          | 25              | 45              | 25       | 110      |

Source: FAO CROPWAT model (Smith & Munoz, 2002).
2.7. Water use efficiency
The water use efficiency was calculated by dividing the harvested yield in kg per unit volume of water used. Crop water use efficiency is the grain yield to crop water use (Kadayifci et al., 2005).

\[ CWUE = \frac{Y(kg/ha^{-1})}{CWU(m^3)} \]  \hspace{1cm} (4)

2.8. Data collection and analysis
The crop data were collected from the middle rows in order to avoid the border effect. Five plants were taken randomly and tagged from the middle rows of each experimental plot for recording and observation of growth and yield parameters. The plants were picked at random carefully from the middle three rows by avoiding one plant from starting and ending of three middle rows. Data regarding different components of growth yield and yield components were recorded.

2.9. Phenology and growth parameters

2.9.1. Days to onion bulb enlargement
Days to onion bulb enlargement were recorded as the actual number of days from the date of transplanting to the time when 50% of the leave plants in each plot showed a change leaves color.

2.9.2. Days to onion bulb harvestable
Days to onion bulb harvestable: were recorded as the onion bulb reached harvestable and all leaves become dried.

2.9.3. Plant height
This was taken from a sample of five randomly selected onion plants marked within each plot. When the plant reaches maturity stage, a carpenter’s tape was used for measuring the height from the ground level to the top-most leaf. The mean from the five plants was then determined.

2.9.4. Leaf Length (cm)
Leaf Length (cm) was taken from a sample of five randomly selected onion plants marked within each plot. When the plant reaches maturity stage, a carpenter’s tape was used for measuring the leaf length from the onion stem to the top-most leaf. The mean from the five plants was then determined.

2.9.5. Leaf diameter (cm)
The diameter of leaves at three different places of the leaves was measured from 10 randomly selected plants using vernier caliper.

2.9.6. Leaf area
The leaf area was determined by the nondestructive length x width method using the relation: Leaf area of onion = 0.837 (length x width) (Juan et al., 2013). Five leaves were measured with a ruler for each plot and the leaf area was determined.

2.9.7. Number of leaf per ear
The number of leaves in five plants from each plot was counted after they had been dried and shelled and was divided by the number of ears to determine the mean.

2.10. Yield and yield components

2.10.1. Weight of bulb (single onion bulb weighed)
The mean weights of the bulb for each onion bulb has taken randomly from the plot.
2.10.2. Diameter of bulb per plant
The diameter measured was the maximum width of the onion in a plane perpendicular to the pole. Bulb diameter was determined as one of the parameters of crop quality (Yemane et al., 2018). The diameter of the matured bulb per plant measured at harvest period on five randomly selected plant samples per plot and averaged per plant wise.

2.10.3. Marketable yield (kg/ha)
 Marketable yield (kg/ha) is healthy and nondiseased average to large-sized Bombay Red onion bulbs were recorded from central three harvestable rows. The marketable onion was sorted out of the total onion bulb depending on the color of the bulb, absence of surface defects on onion (due to insect, disease, or physiological disorders), and firmness.

2.10.4. Unmarketable onion (kg/ha)
 Unmarketable onion (kg/ha) is split, decayed, diseased, and undersized bulbs.

Size category of bulbs (g) was done in accordance with market assessment at Ambo city using the following criteria: small for bulb weights <50 gm, medium for bulb weights between 50 and 120 gm, and large for bulb weights >120 gm. Bombay Red onion bulbs were recorded as the weight of unmarketable onion from central two harvestable rows. Unmarketable onions were sorted out of marketable onion yield depending on the disease on the bulb, discoloration, cracks, damage by insect, the smallness of size, and avoiding unwanted onion by the consumer.

2.10.5. Total bulb yield (kg/ha)
 Total bulb yield (kg/ha) is the sum of marketable and unmarketable bulb yields.

2.10.6. Total biomass yield (kg/ha)
 This was determined by the summation of all the above and underground biomass weights of sample plants.

2.10.7. Harvest index (%)
 This was expressed as the ratio of total bulb dry weight to the total biomass dry weight and expressed in percentage.

\[ HI = \frac{\text{Total bulb dry weight}}{\text{Total biomass dry weight}} \times 100 \] (5)

2.11. Statistical analysis
All necessary data collected were managed properly using the SAS computer package version 8.2. When the treatment effect was found significant, the mean difference was tested using the LSD test at \( P = 0.05 \).

3. Results and discussion

3.1. Climate characteristics of the study area
Each crop has certain environmental requirements. To attain the highest yield (potential yield), a crop must be grown in an environment that meets the requirements. The main climatic element determinant to crop growth and yield includes rainfall, temperature, solar radiation, and wind speed (Ali, 2010).

The pattern of the seasonality of rain in the Ambo area is determined by analyzing the mean monthly rainfall ratio with that of the rainfall module as rainfall amount. This rainfall amount is used to utilize the availability of water to determine the amount and frequency of irrigation. It also used how plants survive the period without rain, frequency of irrigation, and scheduling of irrigation, i.e., how much water to apply and when to irrigate.
Temperature is an important element of weather in crop production. The maximum temperature usually occurs during daytime and minimum during the night. Maximum temperatures, during the day, are important factors to determine potential evapotranspiration. Likewise, minimum temperatures are also useful to identify the occurrence of frost, which consequently decreases the production and productivity of the crop. About eighty (80%) of the total rainfall of the study area occurs from May to September with its peak in the months of July and August. The remaining months receive less rainfall (Figure 2).

Reference evapotranspiration (ETo) of the area is higher during the months of October to May, but low during the months of June to September; consequently, evapotranspiration in the area is high in the months of February, March, April, and May and lowest in the months of July and August (Figure 2).

As transpiration is greatly reduced, leaf temperature is greater than air temperature because of radiation absorbed by the leaf. In agreement with the present result, Disket et al. (2017) who reported that yield and yield components of red onion show that appropriate irrigation treatments would cause a proper translocation of photosynthetic products to the grains unless water stress is severe enough to cause a dramatic decrease of these products in the production.

3.2. Soil of the experimental site
The values of physical and chemical analyses of selected soil parameters of the experimental site are described as the focus.

| Soil depth (cm) | Particle size distribution (%) | Textural class |
|----------------|--------------------------------|----------------|
|                | Sand  | Silt  | Clay  |                  |
| 0–20           | 15.9  | 18.1  | 66.1  | Clay             |
| 20–40          | 16.0  | 17.1  | 66.9  | Clay             |
| 40–60          | 17.3  | 14.4  | 68.3  | Clay             |
| Average        | 16.4  | 16.5  | 67.1  | Clay             |
3.2.1. Soil texture
The results of the particle size distribution are presented in Table 3. The soil is dominated by clay particle size in all soil depths with a slight increase in clay content with depth. Texture class influences the ease with which soil can be worked, the amount of water and air, it holds and the rate at which water can enter and move through the soil. It is best for plant growth because they hold water and provide desirable characteristics (Ali, 2010).

Irrigation scheduling is directly related to the physical properties of soil. The study area is dominated by clay soil. Clay texture soils are the opposite of sand soil and only allow water to enter them very slowly; however, they hold a large amount of water. Thus, the physical properties of a soil control both the rate at which water is applied and the total amount of water to be applied (Ali, 2010).

3.2.2. Soil bulk density and water retention
The results of field capacity, permanent wilting point, bulk density, and total available water are described in Table 4.

High bulk density is an indicator of low soil porosity and soil compaction. It may cause restrictions to root growth and poor movement of air and water through the soil. Compaction can result in shallow plant rooting and poor plant growth, influencing crop yield, and reducing vegetative cover available to protect soil from erosion.

As shown in Table 4, the result of soil moisture content at field capacity varied with the depths. The moisture content is decreased from top-to-bottom depth.

Total available water (TAW) which is the amount of water that a crop can extract from its root zone is directly related to variation in field capacity and permanent wilting point. As a result of the study area, the high value of TAW was found in topsoil, whereas lower values were recorded, in the study area in the subsurface soil.

3.2.3. Soil chemical properties at the experimental site
In addition to physical properties, soils have unique chemical properties as well. The main chemical properties of soil are pH, ECe, salinity, available P, phosphorus, available potassium, carbon to nitrogen ratio (C/N ratio). The soil pH of the study area varied with depth (Table 5). It was relatively higher at subsurface than the surface soil indicating that the soil tends to be alkaline (Jones, 2003).

According to Fikire and Olani (2010), onion plants can grow from neutral to a slightly alkaline conditions. The experimental site, therefore, had a favorable soil pH for onion growth. The ECe of the soil, which ranged from 0.21 at a depth of 0–20 cm to 0.175 at lower depths, indicate that the soil is nonsaline and nonsodic. According to Ecocrop (2003), crops not tolerate saline above (>4dS/m). This indicates that the soil salinity of the experimental site was very low with a negligible effect on the crop.

| Table 4. Soil bulk density, water content (at FC and PWP), and total available water |
|-----------------------------------------------|-----------|---------|--------|----------|
| Soil depth (cm)                              | BD (g cm⁻³)| FC (%)  | PWP (%)| TAW (mm m⁻²) |
| 0–20                                         | 1.09      | 40.45   | 21.53  | 206.23    |
| 20–40                                        | 1.12      | 35.63   | 17.73  | 200.48    |
| 40–60                                        | 1.13      | 29.73   | 17.70  | 135.94    |
| Average                                      | 1.11      | 35.27   | 19.0   | 177.34    |

BD = Bulk density, FC = Field capacity, PWP = Permanent wilting point, TAW = Total available water.
Table 5. Soil chemical properties at the experimental site

| Soil depth (cm) | pH | ECE (dS/m) | OM (%) | Available P (ppm) | Available K (ppm) | Total N (%) |
|----------------|----|------------|--------|-------------------|-------------------|-------------|
| 0–20           | 7.83 | 0.21      | 3.66  | 5.9               | 285.00           | 0.13        |
| 20–40          | 8.13 | 0.18      | 2.09  | 4.3               | 245.00           | 0.10        |
| 40–60          | 8.01 | 0.18      | 2.06  | 3.6               | 226.00           | 0.07        |
| Average        | 7.99 | 0.19      | 2.60  | 4.6               | 252.00           |             |
| Total          |     |           | 0.13  |                   |                   | 0.30        |

ECE = Electrical conductivity, OM = Organic Matter, P = Phosphorous, K = Potassium, N = Nitrogen.

As indicated in the above table, the organic matter content of the soil had average values of 2.6%. The average organic matter content of the soil, determined by the Walkley-Black method, was found to be 2.6% (1.724°C). The highest value of OM was recorded in the top layer. This might be due to the highest crop residue in the soil for the top layer, compared to the subsurface layers. Similarly, the average value of available P, available K, and total N contents of the soil were 4.6 ppm, 252 ppm, and 0.1%, respectively. By depending on reference of Neeraja et al. (1999) who reported that application of nitrogen fertilizer at the rate of 150 kg ha⁻¹ increased biological yield of onion, the study result is not enough for onion production.

3.3. Crop water requirements and irrigation application

Analysis of monthly reference evapotranspiration (ET₀) calculated from historical records of 20 years shows that the minimum reference evapotranspiration (ET₀) is 2.80 mm/day, which occurs in July and August, and maximum ET₀ occurs from October to May (Table 6).

The value of crop coefficient (kc) varied from 0.7 to 1.05 (Table 6). The average crop coefficient throughout the growing seasons was 0.88. The crop water requirement (ETc) throughout the growing season was determined by multiplying the reference evapotranspiration (ET₀) by (kc) based on the Irrigation water requirement.

3.4. Phenology and growth parameters of onion day of 50% bulb maturity

Analysis of variance showed the existence of a significant (p < 0.05) variation on days to enlargement of the bulb due to deficit irrigation and timing.

The results indicate that the influence of deficit irrigation on days of growth of enlargement bulb was significantly different at treatments 100% ETc and 75% ETc leveling and timing, 50% its leveling and timing and 25% ETc depth of water applied plots (Table 7). The difference in the days to enlargement of the bulb within the different deficit irrigation levels could be due to differences in depth of water applied in the respective deficit irrigation levels. Significantly, the longer development of the bulb period in T3 (75% ETc and Skipping irrigation at initial growth stage) and T6 (75% ETc and Skipping irrigation at late growth stage) the growth period, resulting more amount of irrigation water application than other treatments. This could have promoted vegetative growth and delayed the transition to the reproductive period. This study is in agreement with the finding of Guluma (2009) who reported that the length of days to enlargement of the bulb is longer as the frequency and amount of water application increased due to frequent water application, which promoted vegetated growth, and delayed the development period.

3.4.1. Days to harvest

Days to harvest was significantly (p < 0.05) influenced by varying deficit irrigation levels applied and water deficit in the plant growth stage. However, irrigation level and deficit in growth stages did interact to influence days harvesting significantly, days to the harvest of onion was between 88 and 110 days (Table 7).
### Table 6. Net irrigation requirement for all treatments

| Growth stage | Date     | Irrigation interval | ETo (mm/period) | Crop kc | CWR (mm/period) | IR (mm/period) | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T8 | T9 | T10 |
|--------------|----------|---------------------|-----------------|---------|----------------|---------------|----|----|----|----|----|----|----|----|----|-----|
| Init.        | 24-Dec.  | 4                   | 3.21            | 0.7     | 6.7            | 6.7           | 1.7| 0.0| 5.1| 5.06| 5.1 | 0.0 | 3.4| 3.4| 3.4 |
| Init.        | 27-Dec.  | 7                   |                 | 0.7     | 7.3            | 7.3           | 1.8| 0.0| 5.5| 7.32| 5.5 | 0.0 | 3.7| 3.7| 3.7 |
| Init.        | 02-Jan.  | 10                  | 3.5             | 0.7     | 7.9            | 7.9           | 2.0| 0.0| 5.9| 7.32| 5.9 | 0.0 | 4.0| 4.0| 5.0 |
| Init.        | 05-Jan.  | 13                  |                 | 0.7     | 9.2            | 9.2           | 2.3| 0.0| 6.9| 7.32| 6.9 | 0.0 | 4.6| 4.6| 5.6 |
| Init.        | 08-Jan.  | 16                  |                 | 0.8     | 9.9            | 9.9           | 2.5| 0.0| 7.4| 7.32| 7.4 | 0.0 | 4.9| 4.4| 5.9 |
| Dev.         | 12-Jan.  | 20                  |                 | 0.8     | 14.0           | 14.0          | 3.5| 10.5| 0.0| 7.32| 10.5| 7.0 | 7.0| 8.0|
| Dev.         | 15-Jan.  | 24                  |                 | 0.9     | 14.7           | 14.7          | 3.7| 11.0| 0.0| 7.32| 11.0| 7.35| 7.2| 8.4|
| Dev.         | 19-Jan.  | 28                  |                 | 0.94    | 15.1           | 15.1          | 3.8| 11.3| 0.0| 7.32| 11.3| 7.56| 7.4| 8.6|
| Dev.         | 23-Jan.  | 32                  |                 | 1.0     | 14.7           | 14.7          | 3.7| 11.0| 0.0| 7.32| 11.0| 7.35| 7.2| 8.4|
| Dev.         | 27-Jan.  | 36                  |                 | 1.1     | 15.1           | 15.1          | 3.8| 11.3| 0.0| 7.32| 11.3| 7.56| 7.4| 8.6|
| Mid.         | 03-Feb.  | 40                  | 3.6             | 1.1     | 15.1           | 15.1          | 3.8| 11.3| 11.3| 0.0| 11.3| 7.56| 7.6| 0.0| 8.6|
| Mid.         | 08-Feb.  | 45                  |                 | 1.1     | 15.1           | 15.1          | 3.8| 11.3| 11.3| 0.0| 11.3| 7.56| 7.6| 0.0| 8.6|
| Mid.         | 13-Feb.  | 50                  |                 | 1.1     | 18.9           | 18.9          | 4.7| 14.2| 14.2| 0.0| 14.2| 9.45| 9.5| 0.0| 10.5|
| Mid.         | 18-Feb.  | 55                  |                 | 1.1     | 18.9           | 18.9          | 4.7| 14.2| 14.2| 0.0| 14.2| 9.45| 9.5| 0.0| 10.5|
| Mid.         | 23-Feb.  | 60                  |                 | 1.1     | 18.9           | 18.9          | 4.7| 14.2| 14.2| 0.0| 14.2| 9.45| 9.5| 0.0| 10.5|
| Mid.         | 28-Feb.  | 65                  |                 | 1.1     | 18.9           | 18.9          | 4.7| 14.2| 14.2| 0.0| 14.2| 9.45| 9.5| 0.0| 10.5|

(Continued)
| Growth stage | Date       | ETo (mm/period) | Irrigation interval (mm/period) | CWR (mm/period) | Crop kc | IR (mm/period) | T1 | T2 | T3 | T4 | T5 | T6 | T7 | T8 | T9 | T10 |
|-------------|------------|----------------|--------------------------------|-----------------|---------|---------------|----|----|----|----|----|----|----|----|----|-----|
| Mid.        | 02-Mar.    | 70             | 3.62                           | 1.1             | 18.0    | 4.8           | 14.3| 14.3| 14.3| 0.0 | 14.3| 9.5| 0.0 | 9.5| 9.5| 0.0 |
| End         | 08-Mar.    | 76             | 1.1                            | 18.0            | 4.8     | 14.3          | 14.3| 14.3| 14.3| 0.0 | 14.3| 9.5| 0.0 | 9.5| 0.0 | 0.0 |
| End         | 14-Mar.    | 82             | 0.8                            | 18.5            | 4.6     | 13.8          | 13.8| 13.8| 13.8| 0.0 | 13.8| 9.2| 9.2 | 9.2| 9.2 | 9.2 |
| End         | 20-Mar.    | 88             | 0.8                            | 18.5            | 4.6     | 13.8          | 13.8| 13.8| 13.8| 0.0 | 13.8| 9.2| 9.2 | 9.2| 9.2 | 9.2 |
| End         | 26-Mar.    | 94             | 0.8                            | 18.5            | 4.6     | 13.8          | 13.8| 13.8| 13.8| 0.0 | 13.8| 9.2| 9.2 | 9.2| 9.2 | 9.2 |
| End         | 02-Apr.    | 100            | 0.8                            | 18.5            | 18.5    | 13.8          | 7.9 | 7.9 | 7.9 | 7.9 | 7.9 | 5.2| 5.2 | 5.0| 0.0 | 0.0 |
| End         | 08-Apr.    | 106            | 0.8                            | 18.5            | 10.5    | 7.9           | 7.9 | 7.9 | 7.9 | 7.9 | 7.9 | 5.2| 5.2 | 5.0| 5.0 | 5.0 |
| End         | 14-Apr.    | 115            | 0.8                            | 18.5            | 10.5    | 2.6           | 7.9 | 7.9 | 7.9 | 7.9 | 7.9 | 5.2| 5.2 | 5.0| 5.0 | 5.0 |
| End         | 20-Apr.    | 121            | 0.8                            | 18.5            | 10.5    | 2.6           | 7.9 | 7.9 | 7.9 | 7.9 | 7.9 | 5.2| 5.2 | 5.0| 5.0 | 5.0 |
| End         | 26-Apr.    | 127            | 0.8                            | 18.5            | 10.5    | 2.6           | 7.9 | 7.9 | 7.9 | 7.9 | 7.9 | 5.2| 5.2 | 5.0| 5.0 | 5.0 |
| End         | 02-May.    | 133            | 0.8                            | 18.5            | 10.5    | 2.6           | 7.9 | 7.9 | 7.9 | 7.9 | 7.9 | 5.2| 5.2 | 5.0| 5.0 | 5.0 |
| End         | 08-May.    | 139            | 0.8                            | 18.5            | 10.5    | 2.6           | 7.9 | 7.9 | 7.9 | 7.9 | 7.9 | 5.2| 5.2 | 5.0| 5.0 | 5.0 |
| End         | 14-May.    | 145            | 0.8                            | 18.5            | 10.5    | 2.6           | 7.9 | 7.9 | 7.9 | 7.9 | 7.9 | 5.2| 5.2 | 5.0| 5.0 | 5.0 |
| Total       |             | 361.9          | 361.9                          | 361.9           | 361.9   | 361.9         | 361.9 | 361.9 | 361.9 | 361.9 | 361.9 | 361.9 | 361.9 | 361.9 | 361.9 | 361.9 | 361.9 |
The treatments in which deficit irrigation was maintained at 75% ETC and 50% its level required shorter days to maturity than those of 100% ETC, which took significantly longer time for physiological maturity. Treatment that received full irrigation required a longer time to maturity than other treatments, whereas treatment that received 25% ETC required the shortest time to maturity. The remaining treatments were also found to be relatively the same with harvesting dates ranging from 93 to 106 days which significantly differ from each other. As indicated earlier, the 50% ETC and 25% of its deficit received onion bulb enlargement earlier and those earlier enlargements, the earlier it sets bulb and mature earlier (Table 7). This result is in agreement with David et al. (2016) which reported that the time length of harvesting of onion is a direct correlation with the application of water depth and timing.

3.4.2. Leaf length
From the analysis, a significantly difference (P < 0.05) in leaf length observed due to the main effects of irrigation levels and growth stage.

The increasing plant height with adequate depth of irrigation application also indicates the favorable effect of water in maintaining the turgor pressure of the cell which is the major prerequisite for growth (Table 7). On the contrary, shortening of plant height under soil moisture stress may be due to stomatal closure and reduced CO₂ and nutrient uptake by the plants and, hence, photosynthesis and other biochemical process hampered, affecting plant growth (El-Noemani et al., 2009).

This result is in agreement with the finding of Enchalew et al. (2016) who reported that the highest and the lowest plant height of shallot resulted from 0.9% ETC and 0.5% ETC. irrigation levels, respectively. David et al. (2016) and Biswas et al. (2003) also observed that the higher level of irrigation resulted in maximum crop height. The present result is also in agreement with the work of Al-Moshileh (2007) who reported that with increasing soil, water supply, and plant growth parameters (plant height) were significantly increased. Kumar et al. (2007) also reported that irrigation had a significant effect on plant height; which subsequently influenced the crop yield.

3.4.3. Leaf number per plant
The leaf number of onion plants was significantly affected (P < 0.05) by irrigation depth. Significantly, the study revealed that optimum irrigation level at T1 and T3 resulted in the highest number of onion leaves, while the least number of leaves per plant was recorded in plots that received 25% ETC irrigation level.

This result seems closely related to that of David et al. (2016) who obtained a number of leaves per plant of the onion by the interaction effects irrigation levels and skipping irrigation at one growth stage. Biswas et al. (2003) reported that onion bulbs of irrigated treatments gave the highest leaves number per plant than the deficit irrigated one, whereas onion grown without supplemental irrigation gave the lowest number of leaves. The higher leaf number per plant resulted from the application of 100% ETC irrigation depth is due to the irrigation effect that facilitates nutrient availability and photosynthesis for undisrupted growth of the plant (Table 7). Similarly, the reduced number of leaves per plant at 0.5% ETC of irrigation level or depth attributed to the effects of water stress on cell expansion (Abbey & Joyce, 2004). This indicated that when plants respond to water stress by closing their stomata to slowdown water loss by transpiration, gas exchange within the leaf is limited; consequently, photosynthesis and growth would slowdown. The result also in agreement with the findings of Ramada and Ramanathan (2017) who found that leaf numbers had a linear correlation with the availability of soil moisture.

3.4.4. Plant height
Plant length of onion plants was significantly (P < 0.05) influenced by the variation of water application. Based on the result, significantly the longest plant height T1 (full irrigation throughout
### Table 7. Effects of irrigation depths at a different averages of growth stages on onion growth parameters

| Treatments | DM (days) | DH (days) | LL (cm) | NLPP | PH (cm) | LD (cm) | LA (cm²) |
|------------|-----------|-----------|---------|------|---------|---------|----------|
| T1         | 52.00     | 110.67    | 57.93   | 13.87| 68.13   | 2.97    | 111.42   |
| T2         | 42.00     | 88.00     | 40.60   | 9.67 | 43.40   | 0.80    | 250.1    |
| T3         | 49.67     | 104.67    | 56.33   | 13.80| 67.40   | 2.77    | 104.40   |
| T4         | 48.67     | 98.33     | 48.40   | 12.20| 56.73   | 2.07    | 66.87    |
| T5         | 47.00     | 98.67     | 49.67   | 11.13| 60.53   | 2.03    | 62.55    |
| T6         | 50.00     | 101.67    | 55.73   | 11.33| 64.87   | 2.59    | 83.44    |
| T7         | 49.00     | 100.33    | 47.93   | 12.27| 60.93   | 1.63    | 54.00    |
| T8         | 43.33     | 93.33     | 47.53   | 11.07| 58.80   | 1.37    | 44.37    |
| T9         | 42.67     | 92.67     | 41.40   | 9.13 | 47.40   | 1.23    | 35.68    |
| T10        | 49.00     | 100.67    | 49.13   | 12.20| 60.00   | 1.57    | 52.12    |
| LSD(0.05)  | 5.04      | 9.41      | 5.29    | 2.58 | 6.07    | 0.33    | 19.9     |
| CV (%)     | 6.25      | 5.52      | 6.23    | 12.9 | 6.02    | 9.97    | 18.13    |

DM = Days to 50% maturity, DH = Days Harvesting; LL = Leaf length; Number of leaf per plant, PH = Plant height, LD = Leaf diameter, LA = Leaf area treatments of Bombay red onion. Means within a column followed by the same letter(s) are not significantly different at 5% probability.
the growth stage) and T3 that received the optimum amount of irrigation water had the highest plant height. On the other hand, the most stressed crops, i.e., T2 (Skipping irrigation throughout growth stage), which received only one-fourth of the optimum irrigation water throughout the whole growing season had the shortest leaf length. The treatment, T3 by 25% deficit at the initial stage, had a larger plant height compared to other treatments stressed at specific stages (Table 7).

The increase in plant height with increased irrigation water could be mainly due to better availability of soil moisture that has enhanced effects on the vegetative growth of plants by increasing cell division and elongation. The increasing plant height with adequate depth of irrigation application also indicates the favorable effect of water in maintaining the turgor pressure of the cell, which is the major prerequisite for growth (Ramada & Ramanathan, 2017). On the contrary, shortening of plant height under soil moisture stress may be due to stomatal closure and reduced CO2 and nutrient uptake by the plants and, hence, photosynthesis and other biochemical process hampered, affecting plant growth (El-Noemani et al., 2009).

The study is in agreement with the finding of Ramada and Ramanathan (2017) who reported that the highest and lowest plant height of shallot resulted from 1.0 to 0.5 ETc irrigation levels, respectively. David et al. (2016) also observed that the higher level of irrigation (1.2 IW) resulted in maximum plant height, and also the present result was in agreement with the work of Al-Moshileh (2007) and Enhalew et al. (2016) who reported that with increasing soil-water supply, plant growth parameters (plant height) were significantly increased. Similarly, Biswas et al. (2003) reported that onion bulbs of irrigated treatments were bigger, whereas plants grown without supplemental irrigation were significantly shorter. Kumar et al. (2007) also reported that irrigation had a significant effect on plant height; which subsequently influenced the crop yield.

3.4.5. Leaf diameter
The main effects of irrigation application as well as skipping irrigation application in one growth stage significantly influenced the leaf diameter of the onion. Similarly, the two factors also interacted to influence significantly (P < 0.05).

Almost similar to the effect observed in leaf length, with an increase in the water application, the leaf diameter of the onion plants increased significantly across the increasing depth of the water application. Thus, plants treated with water application at the sufficiency of water and no zero water application at any growth stage produced leaves with the widest diameter. However, plants treated with water deficit with 25% of ETc produced leaves with the narrowest diameter (Table 7).

The increase in leaf diameter with the increase in water application and no zero water application at any growth stage could be associated with a better supply of water and less stiff competition for other growth factors among the onion plants. Concurrent with the results of this study, David et al. (2016) also showed that the lowest leaf diameter was recorded for stressed onion. Supporting the current finding, Gebregergis et al. (2016) and Zayton (2007) reported that the smallest onion leaf diameter was recorded at the low-watered treatment.

3.4.6. Total leaf area
Leaf surface area decreases as the amount of water applied to the crop decreases. Differences in the total leaf area per plant (LAPP) were observed among different levels of irrigation water application. There was a highly significant difference among treatments in total leaf area per plant.

Treatments with the almost the optimum amount of irrigation water application had a larger leaf area compared with the stressed one (Table 7). It was reasonable that those, which take full, and a slightly less amount of irrigation water have a larger as well as a broadleaf, since they get a required amount of irrigation water. Those treatments by 25% deficit at the specific stage had a higher leaf area compared to a 50% deficit at specific stages. However, the stressed ones got one-fourth of the required amount of irrigation water throughout the growing season to have a narrow
and small leaf in order to conserve the amount of water lost through transpiration. Similar findings have also been reported by Bagali (2012) that the plant water stress also retards leaf area expansion and reduced leaf area, which is more important to decrease in crop growth.

3.5. Yield and yield-related effects

3.5.1. Total biomass yield

Analysis of variance revealed that total biomass production was significantly (P < 0.05) affected by variation in water application depth and timing.

The total biomass yield of onion, which is the sum of all above and underground biomass, was highly influenced by the interaction of skipping irrigation in the growth stage and deficit in the irrigation level of water treatments (Table 8). The biomass production in the experiment was proportional to the availability of water i.e. as the stress intensity increased, biomass production decreased. This study indicated that the dry biomass percentage (DBP) changed significantly with the amount of applied irrigation water and timing. The DBP was less in the treatments, which is affected by skipping irrigation application and deficit level in the growing season. The DBP reduced significantly in T2 in which 75% water deficit maintained throughout the crop season. The DBP increased progressively up to 110 days in T3 and T6 and the difference was observed in all the treatments.

A maximum biomass yield was obtained from full-watered treatments. However, T3 and T6 were significantly different from T1; total biomass is higher than the other treatments. Whereas minimum biomass yield was obtained from the stressed water throughout the growing season. This result on biomass yield of onion is in agreement with the result of Subedi et al. (2002) who found that the total biomass of onion was significantly reduced at low irrigation level. Similarly, Kumar et al. (2007) and Enciso et al. (2009) found that irrigation affects the total onion yield, yield components, and morphological characteristics of onion bulbs. The reason for the low total biomass yield at 0.5 ETC and 0.25 ETC may be because of the plant’s response of closing their stomata under water stress to slowdown water loss by transpiration; consequently, gas exchange within the leaf is limited and photosynthesis and growth will slowdown. Moreover, the shallow root system of the onion leads to less access to reserve water for the root and thus limits the growth of the plant (David et al., 2016).

3.5.2. Average bulb weight

The Bulb production in the experiment was proportional to the availability of water but as the stress intensity increased Bulb weight decreased. Similarly, the two factors also interacted to influence significantly (P < 0.05) average bulb weight. Bulb weight was affected severely at stress was imposed throughout the growing season and at mid-season stages.

The highest average bulb weight was recorded from plots that received 100% ETC irrigation treatment, while the least average bulb weight was obtained from plots at 25% ETC. The T3 and T6 irrigation levels produced the highest average bulb weight followed by skipping irrigation application at the initial and late-stage (Table 8). This result is also in agreement with the result of David et al. (2016) who reported that the optimum amount of irrigation water application resulted in the highest bulb yield. Whereas the stressed plant, for example, T5 (skipping irrigation at the mid-season stage), which received (75% ETC), amount of water at the initial stage, development stage, and late stage, but skipping irrigation application at the mid-season stage of the growing season resulted in detrimental yield reductions. The yield at treatment 9 (50% deficit with the interaction of skipping irrigation at the mid-season stage) less than which received 50% ETC with the interaction of no watering at the initial stage, development stage, and late-season stage. Those treatments stressed by 50% at one specific growth stage had a higher onion yield compared to 25% ETC throughout the growth stage.
Table 8. Effects of irrigation depths at the different growing stage on average, yield, and yield components of onion

| Treatments | TBY (t/ha) | BW (g) | MTY (t/ha) | UMY (t/ha) | TY (t/ha) | BL (cm) | BD (cm) | DM (%) | HI |
|------------|------------|--------|------------|------------|-----------|---------|---------|--------|----|
| T1         | 67.30      | 79.67  | 42.57      | 4.10a      | 46.67a    | 7.07a   | 7.42a   | 93.0   | 0.6bc|
| T2         | 30.93      | 52.00  | 17.60      | 5.2a       | 22.60a    | 4.63a   | 4.60a   | 50.7a  | 0.6c |
| T3         | 63.37bc    | 71.67  | 39.10      | 4.10b      | 43.20b    | 6.50b   | 6.78b   | 83.0b  | 0.5a |
| T4         | 44.10      | 67.67  | 33.30      | 4.20de     | 37.50d    | 6.27ed  | 6.17ed  | 75.0b  | 0.52de|
| T5         | 38.37d     | 61.67  | 26.93cd    | 4.30cd     | 31.30cd   | 5.80cd  | 5.73cd  | 64.5cd | 0.48b|
| T6         | 59.03c     | 70.67  | 35.0c      | 4.13c      | 39.13c    | 6.43c   | 6.37bc  | 77.4b  | 0.5a |
| T7         | 46.07c     | 68.33  | 28.43c     | 4.30c      | 32.80c    | 6.17bcd | 6.00cd  | 65.6c  | 0.56de|
| T8         | 42.60cd    | 61.33d | 23.70de    | 4.50bc     | 28.20de   | 5.33ef  | 5.30ef  | 54.4de | 0.53db|
| T9         | 32.97c     | 56.67  | 20.87f     | 4.60f      | 25.47ef   | 4.93f   | 4.80f   | 53.7c  | 0.4b |
| T10        | 45.63c     | 63.33d | 25.33fc    | 4.70cd     | 29.70cd   | 5.63ed  | 5.67de  | 59.4cde| 0.53d |
| LSD (5%)   | 5.2        | 4.4    | 4.3        | 0.23       | 4.23      | 0.56    | 0.54    | 8.88   | 0.02 |
| CV (%)     | 6.4        | 3.9    | 8.6        | 3.01       | 7.6       | 5.6     | 5.4     | 7.6    | 2.8  |

TB-total biomass, BW- Bulb weight, MTY- Marketable yield, UMY—Unmarketable yield, TY-Total yield, BL-Bulb length, BD- Bulb diameter, DM- Dry matter, HI-Harvest index.

Means within a column followed by the same letter(s) are not significantly different at 5% probability.
3.5.3. Marketable onion yield

There was a highly significant variation in the yield of onion among the experiments.

The highest marketable onion yield was recorded at T1, T3, and T6, which were statistically the same, and the lowest marketable onion yield, was obtained from the stressed plot (Table 8). From this result, it can be concluded that higher irrigation levels and timing help to increase the vegetative growth of the plant, which has improved an average assimilate available for storage and increased average bulb weight that gave the advantage to increase the marketable onion yield.

In agreement with the present result, Gebregwergis et al. (2016) who reported that the general principle that the response of the crop is generally higher under-irrigated conditions than non-irrigated one. This result is similar to the result of Enchalew et al. (2016) who reported that the increment in marketable onion yield due to the application of irrigation water level could be attributed to the increment in vegetative growth and increased production of assimilate, which is associated with an increment in leaf area index, bulb diameter, and average bulb weight. Also, in agreement with this result, Yenus (2013), Kenneth et al. (2017) and Kumar et al. (2007b) reported that the highest and lowest yield was obtained from 1.2 to 0.5 ETc, respectively, and percentage of commercially important bulbs was considerably higher at irrigation level of 1.20 Ep.

3.5.4. Unmarketable onion yield

The analysis of variance indicated that the unmarketable onion yield of onion was significantly (P < 0.05) affected by irrigation level and timing.

Unmarketable onion yield is significantly similar in T1, T3, and T6. Based on the result, the highest unmarketable onion yield, about (5 ton/ha) was recorded from 25% ETc irrigated plot (T2) which is stressed throughout the growing season. Similarly, under 50% ETc irrigation level and skipping irrigation at mid-growing season produced the highest unmarketable onion yield next to 75% stressed throughout the growing season, while the low yield of unmarketable onion yield was obtained from full irrigation plot (Table 8).

From this result, the yield of unmarketable onion was significantly increased as application water depth levels decreased. Increasing skipping of irrigation duration with increasing water deficit had a negative relationship with the yield of onion. Based on the result, during the mid-growing stage is long and at the mid-season stage the crop is sensitive to water stress. This might be due to the stress of water available during foliage growth and photosynthesis activity that contributes to enlargement of the bulb. The result revealed that the yield of very small bulbs increased with deficit irrigation. Stressed onion crop may result from bulbs too early, produce small-sized bulbs, and thus, produce a high amount of unmarketable yield (Enchalew et al., 2016; Yetagesu et al., 2020). This could be due to the low rate of transpiration caused by stomata closer under moisture stress conditions, which brought about reducing photosynthesis and poor bulb growth and developments. Corresponding to this, Zayton (2007) reported that, plots, which received the lowest volumes of water during the development and ripening growth stages, produced a higher percentage of unmarketable bulbs.

3.5.5. Total onion yield

The total bulb yield, which is the sum of unmarketable and marketable bulb yield, was highly influenced by irrigation depth and timing.

The maximum yield was obtained under T1, T3, and T6 and they were statically the same. Treatment 2, which was subjected to the highest water stress (75% deficit) throughout the all-growing period, resulted in the minimum yield of onion (Table 8). When severe water stress, deficit, and skipping of irrigation at a specific growth stage follow, the crop rapidly depletes the soil, water stored in the root zone, and wilts before the completion of abundant root development at greater soil depth (Asemanrafat & Honar, 2017).
| Treatments | Yield (t/ha) | ETa (mm) | ETa/ETm m(mm) | Ya/Ym | 1-(ETa/ETm) | 1-(Ya/Ym) | ky  |
|------------|-------------|----------|----------------|-------|-------------|-----------|-----|
| T1         | 46.67a      | 361.9a   | 1.00a          | 1.00a | 0.00f       | 0.00f     | 0.0f|
| T2         | 22.60f      | 90.5f    | 0.25f          | 0.41f | 0.75a       | 0.59a     | 0.79f|
| T3         | 43.20g      | 241b     | 0.67b          | 0.92b | 0.33e       | 0.08g     | 0.24f|
| T4         | 37.50d      | 216.2c   | 0.60c          | 0.81c | 0.40de      | 0.19f     | 0.48d|
| T5         | 31.30k      | 163g     | 0.45g          | 0.63g | 0.55f       | 0.37ed    | 0.67k|
| T6         | 39.13o      | 179.7d   | 0.50d          | 0.82d | 0.50d       | 0.18f     | 0.36o|
| T7         | 32.80c      | 160.4f   | 0.44f          | 0.67f | 0.56c       | 0.33e     | 0.59f|
| T8         | 28.20e      | 144.2h   | 0.40g          | 0.56g | 0.60c       | 0.44c     | 0.73o|
| T9         | 25.47e      | 115i     | 0.32i          | 0.49i | 0.68o       | 0.51b     | 0.75o|
| T10        | 29.70k      | 136j     | 0.38i          | 0.60i | 0.62o       | 0.40d     | 0.65o|
| LSD (5%)   | 4.23        | 2.21     | 0.12           | 0.03  | 0.03        | 0.1       | 0.06|
| CV (%)     | 7.6         | 0.25     | 14.2           | 6.4   | 3.8         | 0.24      | 0.3 |

Means within a column followed by the same letter(s) are not significantly different at 5% probability.
The water deficit and timing of growth stages are also supported by David et al. (2016) and Ramada and Ramanathan (2017) observation who conducted an experiment on different vegetable crops. They concluded that the low yield was obtained during the stress throughout the growing season, but deficit irrigation during the initial and the late-season stage of the growing season does not affect the crop yield significantly. Irrigation deficit during the mid-growing stage reduced the yield significantly than stressing the crop during the initial and late-season stages.

Treatment 4 (75% ETc and Skipping irrigation at development stage) and treatment 8 (50% ETc and Skipping irrigation at development stage) received 75% ETc and 50% ETc irrigation, during the initial, mid-season, and late-season stages, respectively. The crop partially recovered from the stress as indicated by its yield significantly higher than that of treatment 5 and treatment 9 (Table 8). The ability of crops to partially recovered from the effect of early water stress has also been observed in other studies (Asemanrafat & Honar, 2017; Metwally, 2011). These studies revealed that under-limited water conditions, it is better to start by subjecting the crop to the deficit at early the season. By doing so, the crop adapted to limited watering conditions with stress not being severely concentrated in any one period.

3.5.6. Bulb diameter

The onion bulb diameter was determined as an indicator of the size and it was found to be significantly influenced (p < 0.05) by applying irrigation water stress levels.

The largest mean diameter was significantly increased from T1, T3, and T6, while stressed treatment gave the smallest diameter, having received the least amount of water throughout the growing season (Table 8). The results indicated that bulb diameter varied proportionally with the irrigation water applied and timing. The relation between diameter and irrigation water applied and timing indicating that an increase in bulb diameter in different treatments was attributed to an increase in the application of water and timing applied, hence water applied and timing influences onion size.

These results are in agreement with the result of Kumar et al. (2007b) who reported that irrigation at 1.20 Ep resulted in the highest bulb size. Similarly, with David et al. (2016) reported that a higher level of irrigation 1.0 IW no stress of water in the growing stage resulted in maximum bulb diameter, which is in line with the present result.

3.5.7. Harvest index

Analysis of variance indicated that the harvest index significantly influenced by the main effect of irrigation depth treatments. Irrigation levels of 50% and 25% ETc (75% stress of water throughout the growing season), statistically decreased the harvest index, compared with 75% (zero, watering at initial and late season) and 100% ETc of irrigation water, respectively. On the other hand, at 100% ETc irrigation level, the highest value (0.6) of harvest index of onion was recorded; while the lowest value 0.5 and 0.4 were obtained from 50% to 25% ETc irrigation water, respectively, however no significant difference between 50% and 75% ETc irrigation levels (Table 8). The result in response to irrigation regime was similar to that of Yenus (2013) who reported that increasing the amount of irrigation statistically increased the harvest index of onion.

3.5.8. Bulb dry matter content

Analysis of variance revealed that variation in the level of irrigation water application significantly (P < 0.05) influenced the bulb dry matter of onion.

Total onion bulb production in the experiment was proportional to the availability of water but as stress intensity in deficit and timing increased total onion yield decreased. The bulb dry matter of onion was affected severely when stress was imposed throughout the growing season with low irrigation frequency.
This study is in agreement with the result of Ramada and Ramanathan (2017) reported that water deficit at any growth stage of onions results in dry matter yield reduction, which could possibly due to limitation in assimilate production and accumulation in bulbs under stress conditions. The present result of dry matter of onion is also in agreement with the findings of Kumar et al. (2007b) reported that irrigation at 1.20 Ep (highest water supply) produced a higher dry matter yield. On the contrary, Yetogesu et al. (2020) reported that the volume of water intake in irrigation did not affect the dry matter yield.

3.5.9. Colour and texture
Different levels of water applications had no effect on the Onion color. The color and texture of the harvested crop of onion were red on the outer skin, purple, white flesh, and red inner scales (Figure 3). The present result of bulb color of onion is in agreement with the findings of Sahin and Sumnu (2006) who reported that the skin color of the produced onion bulbs matched the description of the red creole onion by the supplier. Depending on all treatment results, it was therefore apparent that water deficit watering treatment on onion did not affect the color and texture of onionskin and flesh (Figure 3). The color and texture remain attractive to the eye and is attractive to the consumer.

3.6. Yield response factor (Ky)
The relationship between relative yield reduction and relative evapotranspiration deficit for onion yield is significantly positively correlated in all treatments (Table 9). The magnitude of Ky value indicates, the sensitivity of the irrigation practice for water stress and subsequent yield decrease. Result analysis of yield and water shows that the highest Ky were obtained at 75% deficit throughout the growing season, 50% deficit, and skipping irrigation at development and mid-season growth stage, 25% deficit, respectively (Table 9). This indicates that the highest value of Ky, the more the tolerance of the crop to water stress. The lowest was observed 25% deficit and skipping irrigation at initial and late-season stage indicates that the tolerance of the crop to water deficit, and under these lines, these treatments are most economical advantage treatment combination. This shows that the treatment combination can resist the yield decrease associated with water deficit.

The result obtained was in agreement with those reported by Abdel-sattar et al. (2019) and Musa et al. (2019) who said that yield response factor (Ky) value is high under deficit irrigation during the
mid-growing stage. This result indicated a high impact of soil-water stress treatment on the onion yield. Therefore, water management and timing of onion is extremely important at all stages of plant development due to its influence on onion yield and consequently on the quality.

4. Summary and conclusions

Onion (Allium cepa L.) is a widely recognized cash crop and most successfully produced under-irrigated conditions in different parts of Ethiopia, but due to information and irrigation systems the productivity of the crop is much lower. The objective of this study was, to study the effect of the use of efficient irrigation on yield and WUE.

The experiment was designed as ten-treatment combinations replicated three times under Completely Randomized Block Design (RCBD). The effect of irrigation treatments was evaluated through growth parameters, yield, and yield components like plant height, total yield, and marketable yields at (p < 0.05) significance level. Those treatments, which received an optimum amount of irrigation water or a slightly less amount, had prolonged days to maturity whereas those, which received only one-fourth of full irrigation, requirement throughout the growing season had matured earlier.

Based on the results obtained from one cropping season, the following recommendations are made: Onion response to water deficit has a major importance for establishing the priorities in water application in areas when water shortage prevails. Thus, it is recommended that all possible efforts be made to introduce the technology to the farming community since the use of deficit irrigation and zero, watering at initial and late-season stage methods save a reasonable amount of water without affecting the production in moisture deficit season using appropriate a given crop. However, further studies should be made to identify potentially suitable crops for deficit irrigation and tolerant of the growth stage of the crop at the deficit level and skipping irrigation application.

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