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Research Article

Effect of the Irrigation Interval and Nitrogen Rate on Yield and Yield Components of Onion (*Allium cepa* L.) at Arba Minch, Southern Ethiopia

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Onion (*Allium cepa* L.) is an important cash crop for smallholder farmers in the Central Rift Valley of Ethiopia. However, its productivity is low, owing to a number of factors including inappropriate irrigation water and nitrogen management. A field experiment was, therefore, conducted at Amibara farm, Arba Minch, Ethiopia, during the 2018/19 dry season to determine the effect of the irrigation interval and nitrogen rate on growth, yield, and yield components of onion (Bombay Red variety). The treatments comprised four irrigation intervals (3, 6, 9, and 12 days of crop water requirement, ETc) and four nitrogen levels (0, 50, 100, and 150 kg·N·ha^{-1}). The experiment was laid out in a split-plot design using irrigation intervals as main plots and nitrogen rates as subplots with three replications. The growth parameters, yield components, and final yield of onion were significantly higher with 3 and 6 days irrigation intervals (which were statistically similar) than 9 and 12 days irrigation intervals. The increasing N rate significantly increased the growth and yield components up to 150 kg·N·ha^{-1}, but the response was significant only up to 100 kg·N·ha^{-1} on the final yield of the crop. The growth and yield contributing parameters, showing enhancement with frequent irrigation and higher N rates, had a significant bearing on the final yield of onion. The irrigation at 6 days interval combined with 100 kg·N·ha^{-1} gave a higher marketable yield (30.21 t·ha^{-1}), net return (Birr 288,458 ha^{-1}), and marginal rate of return (8586%). As such, irrigation at an interval of 6 days and fertilizer N at the rate of 100·kg·ha^{-1} may be recommended for higher productivity and profitability of onion at Arba Minch, Gamo Zone, southern Ethiopia.

1. Introduction

Onion (*Allium cepa* L.) is one of the most popular vegetables grown around the world for its large benefits [1]. It is believed to be originated in south-western Asia, from where it got spread to the rest of the world. It has been cultivated for over 4700 years as an annual for bulb production. According to FAO [2], China is the top producer of onions in the world followed by India and the USA. The total annual production in 2019 by the top 20 countries that produced most of the onion was 80.04 million tons, the share of China, India, and the USA being 24.97, 22.82, and 3.17 million tons, respectively. The other 17 countries produced more than 1.36 million tons each in 2019. In Africa, Egypt is the leading country producing 3.08 million tons per annum and ranks as the fourth world producer [2].

In Ethiopia, onion is produced in many parts of the country by small and large commercial growers [3]. It has become popular among producers because of its yield potential, ease of propagation both by seed and bulb, and the large demand in domestic and international markets [4]. The national production of onions has been increasing over the years, being 169.3, 219.7, 264.8, and 327.5 thousand metric tons of dry bulb per annum in 2010, 2013/14, 2015/16, and 2016/17 cropping seasons, respectively [5–8]. The yield increase over the years was, primarily, due to an increase in area from 24.4 thousand ha in 2013/14 to 29.5 thousand ha in 2015/16 and to 33.6 thousand ha in 2016/17. The cultivation of onions is concentrated in the Central Rift Valley of the country, particularly in the upper Awash and Lake Ziway areas [9]. The production in Southern Nations Nationalities and People's Region (SNNPR) was about 13.3 thousand tons, the share of Gamo Gofa Zone being only 4.1 thousand tons [8].

Onion cultivation is an important component of commercialization for rural and urban people and is a source of daily income for small farmers. The crop can be cultivated twice a year, both under irrigation and rainfed conditions, in different parts of the country. The consumption of the crop is very important in food seasoning, daily stews as well as different vegetable food preparations [10]. Besides improving the taste and scent of the food [9], it has several medicinal and health benefits, because of the presence of chemical flavonoids, anthocyanins, fructo-oligosaccharides, and organo-sulphur compounds [11].

Given the large demand for onions in domestic and international markets and its importance in sustaining the economy of farming communities, there is a need for increasing its production in Ethiopia both by increasing productivity and bringing more areas under cultivation. Seeing the figure of onion productivity for Ethiopia as $9.7\,t{\cdot}ha^{-1}$ compared to figures of 22.0, 16.2, 56.4, and $36.7\,t\,ha^{-1}$ for China, India, USA, and Egypt [12], there is ample scope for raising the onion production following best management practices. It is heartening to note that the Government of Ethiopia has reaffirmed its commitment to the agricultural sector by scaling up the management practices that enhance the productivity of farms [13].

The low productivity of onions in Ethiopia could be ascribed to a host of agronomic, environmental, and management factors, with the irrigation and fertilization being the important ones [14, 15]. Presently, both water and nutrients are not properly managed, resulting in crop yields far below their potential. Onions have a large water requirement and the shallow root system is, generally, more susceptible to water stress as compared to other crops. Also, onions producing large biomass would have high nutrient requirements, especially nitrogen. Therefore, proper water and nutrient management is considered one of the strategies for enhancing the productivity of onions [15].

The studies over the years have indicated a significant increase in the growth and yield of onions with higher levels of irrigation and short irrigation intervals [16–21]. For instance, Samson and Ketema [17] obtained the maximum yield of onion with full irrigation at Sekota Agricultural Research Center, Woleh, Ethiopia. Muhammad et al. [18] reported the yield components of onions (bulb diameter and bulb weight) to be significantly higher with irrigation intervals of 3 and 6 days than 9 and 12·days at Zuru, Northern Guinea Savanna of Nigeria. Further, in a recent study by Ayza and Ayana [19], the highest bulb yield was obtained in treatment receiving frequent irrigation at 3 and 5 days interval with a higher level of irrigation (100% ETc) at Arba Minch, Ethiopia.

A number of studies have also been carried out to evaluate the effect of N levels on the growth and yield of onions. Applied N doses fluctuate from about 50 to above $200\,kg{\cdot}ha^{-1}$, depending on the region, type of growing onion, and other production practices, like irrigation [22]. For instance, Abdissa et al. [23] found the application of $69\,kg{\cdot}N{\cdot}ha^{-1}$ to be adequate for the growth and bulb yield of onions in Shewa Robit, Ethiopia. Kiros and Nigussie [24] obtained a significant effect of N application on bulb yield up to $100\,kg{\cdot}ha^{-1}$ at Tahtay Koraro, Ethiopia. Furthermore, Yohannes et al. [25] found a relatively higher rate of $150\,kg{\cdot}N{\cdot}ha^{-1}$ to be optimum for onion production in the Jimma area. Therefore, the recommendation on the N rate could not be universal and required to be worked out for different agroecological zones.

There is still little information on the irrigation scheduling and optimum fertilizer N rate for onion production in the Arba Minch area. The farmers practice conventional flood irrigation and apply N fertilizer at a blanket rate of about $64\,kg{\cdot}N{\cdot}ha^{-1}$ (through 100 kg NPS + 100 kg urea). Furthermore, the optimum nutrient rate, preferably, needs to be based on the interactive effect of irrigation and nutrient, as both inputs are linked, and failure to manage one affects the other or improvement in one could enhance theefficiency of the other [26].

Among the recommended onion cultivars by Melkasa Agricultural Research Center, Bombay Red is the most widely grown variety under irrigated conditions in the country due to its qualities of early harvest and good bulb yield [27]. The present study, therefore, aimed at finding an appropriate irrigation interval and nitrogen rate for the Bombay Red cultivar under the agroecological conditions of Arba Minch, Gamo Gofa Zone, southern Ethiopia. Needless to say, the finding will have a great effect on the realization of potential yields and economic benefits of the onion crop in the area.

2. Materials and Methods

2.1. Description of the Study Area

2.1.1. Location. The field experiment was conducted at Amibara in Arba Minch district, Gamo zone of Southern Nations, Nationalities and Peoples` Regional (SNNPR) State during the 2018/19 cropping season. The study area (Figure 1) is geographically located between 37°31′-37°37′E longitude and 5°58′- 6°60′ N latitude. The altitude of the area is 1218 masl. It is 505 km south of Addis Ababa and 250 km from the Regional Capital city of Hawassa.

(1) Climate. The rainfall pattern of the study area was bimodal (Figure 2) with peaks in April and October and a mean annual rainfall of 946 mm. The average maximum and minimum temperatures were 31.4 and 18.0°C, respectively. The rainfall during the crop growing season (Dec–Feb) of 2019 was scanty, and maximum and minimum temperatures were 30–35 C and 15–17 C, respectively (Figure 3). The average daily ETo was 4.13 mm/day, with a peak of 4.9 mm/day in March. The mean annual total evapotranspiration was 1507.5 mm. This implied that evapotranspiration was greater than rainfall and there was a need to supplement soil moisture by irrigation for the growing of crops.

(2) Soil Characteristics. The soil of the research site is alluvial in nature, laid in the past by the Kulfo River that drains in the adjoining Chamo lake. The texture of the soil in 0–60 cm

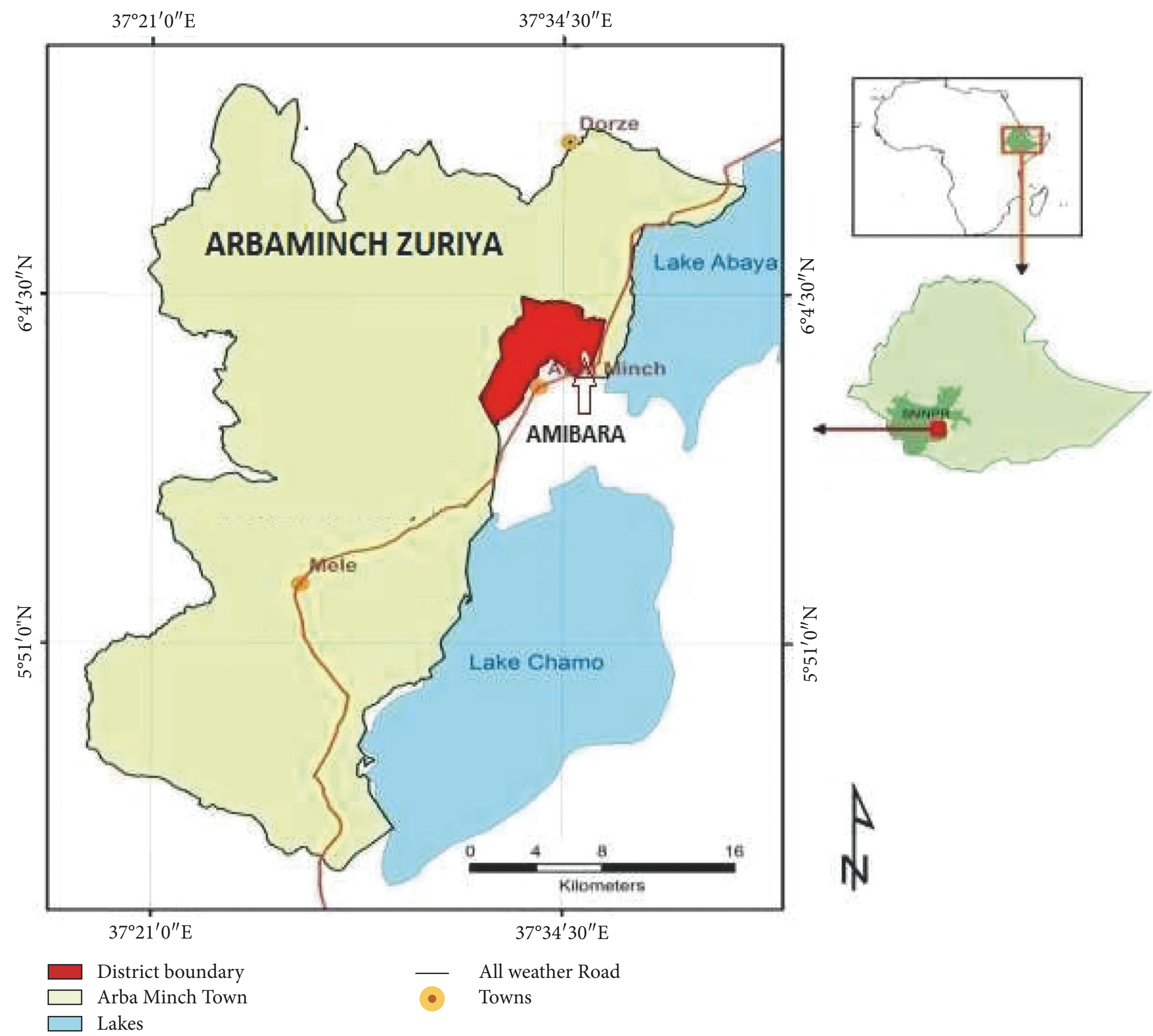

FIGURE 1: Map of the study area.

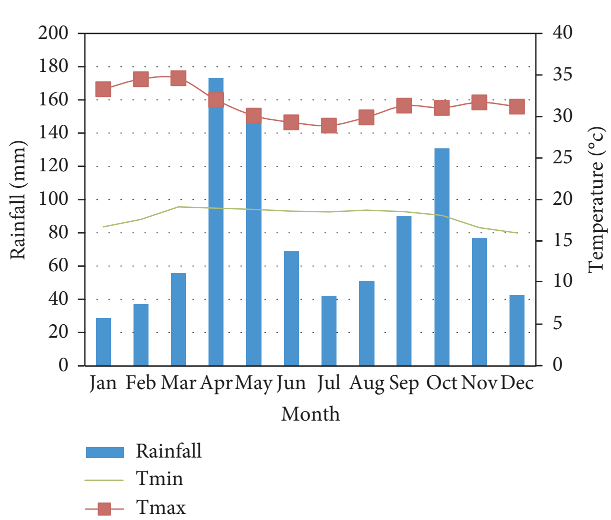

FIGURE 2: Average monthly rainfall and temperature (1987–2018) for Arba Minch district. Source: National Meteorological Agency (2018).

depth was fine (Table 1). The values of field capacity and permanent wilting point were around 40 and 25 percent, respectively. The available water was 25.6, 42.9, and 80.4 mm for 0–15, 15–30, and 30–60 cm depths, respectively. The bulk density of the soil was around 1.30Mgm^{-3}. The soil with a pH value of 6.37 (Table 2) was neutral in reaction for practical purposes. The soil with EC of 0.23 dS·m^{-1} was nonsaline in nature. The contents of total nitrogen (0.21%), organic carbon (1.67%), and available phosphorus (5.57 mg·kg^{-1}) were low as rated by Ethio SIS [28]. The content of available sulphur (25.6 mg·kg^{-1}) was optimum. The irrigation water drawn from the Kulfo River, having values of pH, EC, and total dissolved salts as 7.5, 0.19 dS·m^{-1}, and <1000 mg·l^{-1}, respectively, was categorized as fresh and suitable for irrigation purpose [29].

2.2. Treatments and Experimental Design. There were 16 treatments comprising different combinations of four irrigation intervals (3, 6, 9, and 12 days) of crop water

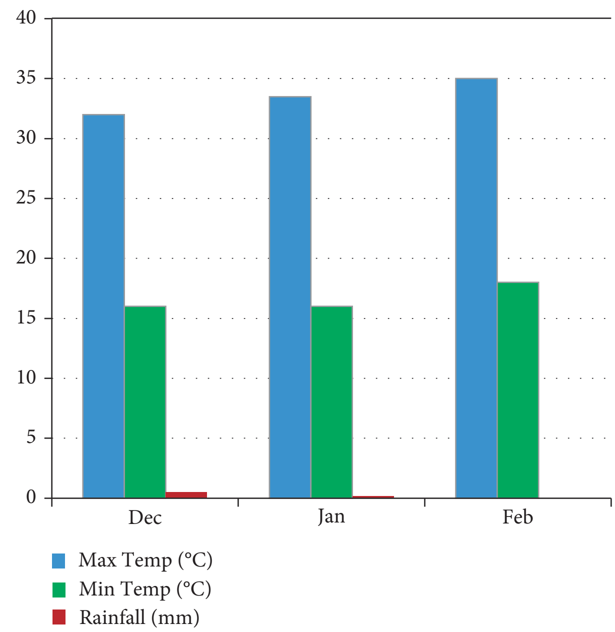

Figure 3: Three months of meteorological data of cropping season. Source: Arba Minch Meteorological Station (2018/2019).

Table 1: Physical properties of the experimental soil.

Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Textural class (USDA)	FC (%)	PWP (%)	TAW (mm)	Bulk density (Mg m^{-3})
0–15	12.96	47.15	39.89	Silty clay loam	42.00	24.90	25.90	1.29
15–30	12.06	39.20	48.74	Silty clay	40.40	26.10	42.90	1.30
30–60	10.34	38.00	51.66	Clay	38.90	25.50	80.40	1.33

FC = field capacity, PWP = permanent wilting point, and TAW = total available water.

Table 2: Chemical characteristics of the experimental soil (0–30 cm).

Soil characteristic	Value	Rating
pH	6.37	Slightly acidic
Electric conductivity (dS m^{-1})	0.23	Salt-free
Organic carbon (%)	1.67	Low
Total N (%)	0.21	Low
Available phosphorus (mg kg^{-1})	5.57	Low
Available sulphur (mg kg^{-1})	25.62	Optimum

requirement (ETc) at different crop growth stages and four nitrogen rates (0, 50, 100, and 150 kg·N·ha^{-1}). The experiment was laid out in a split-plot design, using irrigation intervals as the main plots and nitrogen rates as subplots, and replicated three times. The Bombay Red long day variety, responding favourably to irrigation and N, was used in the study. The amount of irrigation water was applied in accordance with the computed crop water requirement with the help of the CROPWAT model software program. CROPWAT is meant as a practical tool to carry out standard calculations for reference evapotranspiration, crop coefficient (kc), crop water requirement, and crop irrigation amount. The onion plants were planted in the plots using double rows with spacing of 40 cm between ridges, 20 cm between the double rows, and 10 cm between plants (40 cm × 20 cm × 10 cm) including an irrigation water path used for watering the plant for furrow irrigation system (Figure 4). Each experimental plot was 3 m in length and 2.20 m in width, having an area of 6.6 m^2. With 3 double rows (6 single rows) and 28 plants per row, the total plants per plot were 168. The distances between subplots, main plots, blocks, and borders were 0.5 m, 1.5 m, 1.5 m, and 1.5 m, respectively, and the total experimental area was 719.55 m^2.

2.3. Experimental Procedure. The seedlings of onions were raised following proper management practices as suggested by EARO [30]. Seedlings were hardened before transplanting to the main field to enable them withstand the field conditions. The 45 days old healthy and vigorous seedlings were transplanted on November 24, 2018. After transplanting, three full irrigations at three days interval were applied uniformly to all plots, in order to ensure good plant establishment. Immediately after crop establishment, the irrigation was applied to individual plots according to the treatment requirement using a Parshall flume. Urea was used as a source of N; half of the N dose was applied at the time of transplanting and the remaining half was side-dressed after 45 days of transplanting. The P fertilizer at the rate of 92 kg P_2O_5 ha^{-1} was applied uniformly to all plots at the time of transplanting using triple superphosphate. The uniform field management was carried out on all plots as per the recommendations of

Figure 4: View of experimental plots, irrigation water measurement and recording of growth and yield of onion. (a) Experimental plots. (b) Irrigation water measurement by a parshall flume. (c) Measurement of plant height. (d) Measurement of bulb diameter. (e) Recording bulb weight. (f) Recording bulb yield in the plot.

EARO [30]. The irrigation was applied up to February 10, 2019, and discontinued thereafter, i.e., 15 days before harvest.

2.4. Determination of Irrigation Requirement. The irrigation requirement was worked out employing the CROPWAT model, using climatic, soil, and crop data inputs. The reference evapotranspiration (ETo), based on the FAO Penman–Monteith method, was calculated employing 31 years long term climatic data (obtained from National Meteorological Agency, Ethiopia), which included maximum and minimum temperatures, relative humidity, wind speed, and sunshine hours. The crop coefficient (Kc) values based on root depth, critical depletion fraction (p), yield response factor (ky), and plant height of onion were adopted from the FAO Irrigation and Drainage Paper No.56 and the findings of Gobena et al. [31]. The average length of the growing period of the onion crop was taken as 98 days. The Kc values differed with initial, development, mid, and maturity crop growth stages spanning over 16, 31, 29, and 22 days, respectively. The net and gross irrigation requirements for the treatments at different intervals were calculated as follows:

$$\mathrm{NIR} = ETo \times Kc, \tag{1}$$

where NIR = net irrigation water requirement, ETo is reference evapotranspiration, and Kc is the crop factor. The amount of rainfall received, if any, after the last irrigation was deducted from the NIR calculated for a particular irrigation interval.

$$GIR = \frac{NIR}{Ea}, \quad (2)$$

where GIR = gross irrigation requirement, NIR = net irrigation water requirement, and Ea = water application efficiency. The field water application efficiency was assumed to be 60%.

2.5. Irrigation Application. The irrigation water, diverted from the Kulfo River, was brought to the field using a field channel that ran adjacent to experimental plots. The Parshall flume having an opening diameter of 5 cm, length of 3 m, and a head range from 3–10 cm was used to apply irrigation (Figure 4). The flume was set on a straight section of the channel and positioned at a distance of 3 m from the nearby plot to attain a steady flow of water, for all the replication sites. A plastic scale was pasted permanently to the side wall of the flume to take readings. The required amount of irrigation water estimated by CROPWAT was diverted to the furrow after having calibrated the flume for flow rate. The time required to deliver the desired depth of water into each plot was calculated using the following equation:

$$t = \frac{Ig \times w \times l}{60 \times q}, \quad (3)$$

where Ig = gross depth of water applied (mm), t = application time (min), l = plot furrow length (m), w = plot width (m), and q = flow rate (l/s) at a specific Parshall flume head.

2.6. Crop Growth and Yield Data Collection. The data on growth- and yield-related parameters were recorded at physiological maturity (Figure 4) and expressed as the average of 5 plants randomly taken from the central 2 rows of each plot. Yield data were determined on a net plot basis. The data are related to the following parameters:

(1) Plant height (cm): measured from the ground to the tip of the leaves
(2) Leaf number per plant: the average number of leaves per plant
(3) Leaf length (cm): the average length of the longest leaves
(4) Days to maturity: number of days from date of transplanting to 70% of plants showing neck fall
(5) Bulb length (cm): the average length of bulbs measured using a caliper
(6) Bulb diameter (cm): measured at the widest point in the middle portion of the mature bulb using a slide caliper
(7) Bulb weight (g): average weight of bulbs using a digital balance
(8) Total biomass yield (t ha^{-1}): referred to all above and underground biomass from the net plot at harvest
(9) Marketable bulb yield (t ha^{-1}): yield of onions (>3 cm in diameter), free from physiological disorders and pest damage, from the net plot
(10) Unmarketable bulb yield (t ha−1): yield of small-sized (<3 cm in diameter), discolored, physiologically disordered, andpest-damaged bulbs from the net plot
(11) Harvest index: determined as the percentage of the dry bulb weight to the dry biological yield of the onion:

$$\text{Harvest index (HI) (\%)} = \frac{\text{total bulb dry weight}}{\text{total biomass dry weight}} \times 100. \quad (4)$$

2.7. Economic Analysis. To assess the costs and benefits associated with different treatments, the partial budget technique as described by CIMMYT [32] was followed. The costs included the cost of irrigation, fertilizer, seed, and labor for carrying out different operations. The prevailing prices for commodities and labour during experimentation and at harvest were used to work out the total variable cost and gross benefit. The net benefit was calculated by subtracting the total variable cost from the gross benefit. The marginal rate of return (%) was calculated as follows:

$$\text{MRR (\%)} = \frac{\Delta NI}{\Delta VC} \times 100, \quad (5)$$

where ΔNI is a marginal increase in net benefit and ΔVC is marginal increase in variable cost.

2.8. Methods of Data Analysis. The data on growth, yield, and yield components were subjected to analysis of variance (ANOVA), using the SAS computer software program (Version 9) and treatment means were compared using the Duncan's multiple range test at $P < 0.05$ probability level. The relationship between the different parameters was obtained by determining coefficients of correlation ("r") using the SPSS software program (version 16).

3. Results and Discussion

3.1. Effect of the Irrigation Interval and N Rate on Growth Parameters of Onion. The irrigation intervals of 3 and 6 days did not show a significant difference in plant height, leaf number per plant, and leaf length of onion (Table 3). However, the difference in growth became quite evident as the irrigation interval increased from 6 to 9 days and further from 9 to 12 days. Accordingly, the values of growth parameters were significantly higher under 3 and 6 days irrigation intervals compared to 9 and 12 days irrigation intervals. The plant height, leaf number, and leaf length indicated an increase of 22, 89, and 17 percent, respectively, as the irrigation interval reduced from 12 to 6 days. The results are corroborated by the findings of Gwandu and Idris [33] in Bunza Kebbi State, Nigeria, that 3 days irrigation interval had produced significantly the highest number of leaves and growth rate of onions than that by 5, 7, and 9 days irrigation intervals, which meant the shorter irrigation interval maintained soil moisture regime in the root zone closer to field capacity with no moisture stress at any stage of growth and development. An improvement in the growth of spring onion as reflected in increased leaf length on irrigation to near field capacity compared to deficit irrigation (≤50% or ≤ 25%) has also been reported by Abbey and Joyce [34]. Similarly, an increase in irrigation level (reflected in IW/CPE ratios of 0.60, 0.80, 1.0, and 1.2) had a significant effect on the growth parameters of onion [35]. The higher water supply increased the plant height and the number of leaves per plant in a study in Egypt [36]. A recent study at Melkassa Agricultural Research Center, Ethiopia, has indicated a significant increase in the number of leaves per plant of onion at higher irrigation levels (90% of crop water use, ETc) compared to deficit irrigation levels (80, 70, 60, and 50% of ETc) [37].

Under water stress, water uptake into the cytoplasm and vacuole of the cell decreases, reducing thereby cell expansion, leaf elongation, and net photosynthetic area [38]. Further, the deficit of water results in the closure of stomata and reduced assimilation of carbon dioxide, affecting the photosynthetic rate per unit of leaf area and overall growth of plants [39, 40].

As far as the N fertilization effect (Table 3) is concerned, each successive N rate i.e. 0, 50, 100, and 150 kg N·ha^{-1} resulted in a significant increase in plant height and leaf length. Also, the leaf number was influenced significantly up to 100 kg·N·ha^{-1}. The increase in plant height and leaf length at 150 kg·N·ha^{-1} compared to zero N was 16 and 17.2 percent, respectively. Similarly, an increase in leaf number per plant at 100 kg·N·ha^{-1} compared to zero N was 20.7 percent. The results are corroborated by the findings of Zakirullah et al. [41] and Kiros and Nigusse [24] who obtained significantly higher leaf lengths of 54.48 and 52.14 cm at a rate of 150 kg·N·ha^{-1} under agroclimatic conditions of Peshawar, Khyber Pakhtunkhwa, and Tahtay Koraro, Ethiopia, respectively. Tekle [42], however, obtained the tallest plants (46.70 cm) of onion at a relatively lower rate of 82 kg·N·ha^{-1} in the central zone of Tigray, Ethiopia. Similarly, the application of 69 kg·N·ha^{-1} increased plant height and leaf length by about 10 and 11.5%, respectively, over the unfertilized check [23]. The number of leaves increased by about 8% in response to the application of 92 kg·N·ha^{-1} over the control.

The positive effect of N on plant growth may be attributed to its role in the synthesis of chlorophyll, enzymes, carbohydrates, and proteins, essential for vegetative growth [43]. According to Kokobe et al. [25], the higher N fertilization was related to the production of new shoots and vigorous vegetative growth.

The interaction effect of irrigation interval and N rate further indicated higher plant growth with a shorter irrigation interval combined with a higher N rate (Table 4). The plant height was significantly higher with a combination of 3 days irrigation interval and N rate of 150 kg·ha^{-1} than rest of the other combinations. Likewise, the leaf number per plant was significantly higher with a combination of 3 days irrigation interval and N rates of 100 and 150 kg·ha^{-1}. Similarly, Gebregwergis [44] also obtained the longest plant height with a treatment combination of 100% ETc and 138 kg·N·ha^{-1}. The lowest plant height and leaf number were recorded with a combination of 12 days irrigation interval and no fertilization. The frequent irrigation combined with a higher N rate, therefore, ensured optimum growth of onion plants, conditioned by the normal functioning of photosynthesis and other biochemical processes.

Like other growth parameters, the maturity of the crop was markedly influenced by the irrigation interval and N rate. It was significantly reduced with an increase in each irrigation interval and enhanced with an increase in each N rate (Table 3). Accordingly, the irrigation intervals of 3 and 6 days combined with N rate of 150 kg·ha^{-1} and the irrigation interval of 3 days combined with N rate of 100 kg·ha^{-1} significantly enhanced the maturity of the crop (105–106 days) compared to rest of other combinations (Table 4). The longer irrigation interval of 12 days with zero N recorded significantly lower days to maturity (82 days) compared to other treatments. The delay in maturity of crop under frequent irrigation and higher N rate could be ascribed to more availability of growth resources and, thereby, continued physiological activity and growth of plants for more time. Conversely, plants under water and N stress tend to complete their life cycle a few days earlier than those under normal conditions. Similar observations on maturity of onions have been reported by other workers. For example, N fertilization regardless of rate (0, 69, 92, 115, and 138 kg·ha^{-1}) extended days to physiological maturity by about 6 days over the control on vertisol of Shewa Robit, northeast Ethiopia [23]. In another study [45], the physiological maturity of onion increased with successive N rates (0, 23, 46, 69, 92, 115, and 138 kg·N·ha^{-1}), reaching about 118 days at N rate of 138 kg·ha^{-1} compared to 102 days for control in Gode, southeastern Ethiopia. Further, the maturity of plants grown at the rate of 123 kg·N·ha^{-1} under wider intrarow spacing of 12.5 cm required 127 days compared to 100 days under zero N with a narrow intrarow spacing of 2.5 cm, exceeding by about 27% in the former than the latter, in central Tigray region, Ethiopia [42].

3.2. Effect of the Irrigation Interval and N Rate on Yield Components of Onion. As seen from the main effects, the bulb length of onions was the highest under 3 days irrigation interval and decreased significantly, thereafter, with each irrigation interval of 6, 9, and 12 days (Table 5). The bulb diameter and bulb weight were higher with 3 and 6 days irrigation intervals and decreased significantly with successive irrigation intervals. Accordingly, the increases in bulb length, diameter, and weight were 31, 35, and 97 percent, respectively, with 3 days irrigation interval compared to 12 days irrigation interval. The results corroborated with the findings of Gwandu and Idris [33] in Bunza Kebbi State, Nigeria, that the 3 days irrigation interval had produced significantly higher bulb diameter and bulb weight than 5, 7, and 9 days irrigation intervals, and by Muhammad et al. [18] at Zuru, Northern Guinea Savanna of Nigeria that

Table 3: Effect of the irrigation interval and N rate on growth parameters of onion (main effects).

Treatment	Plant height (cm)	Leaf number per plant	Leaf length (cm)	Days to maturity
Irrigation interval (day)				
3	60.80a	12.07a	49.15[a]	101.00a
6	60.25a	11.88a	49.82[a]	99.42b
9	54.57b	8.92b	46.92[b]	89.42c
12	49.26c	6.30c	42.66[c]	84.42d
CD(<0.05)	1.95	0.37	1.66	0.82
SEM (±)	3.79	0.14	2.75	0.66
CV (%)	3.46	3.76	3.52	0.87
N (kg·ha^{-1})				
0	51.67d	8.63c	43.18[d]	89.25d
50	55.40c	9.74b	45.80[c]	92.08c
100	57.91b	10.39a	48.92[b]	95.67b
150	59.92a	10.42a	50.65[a]	97.25a
CD (<0.05)	0.99	0.18	1.22	0.95
SEM (±)	1.40	0.05	2.06	1.20
CV (%)	2.11	2.19	3.07	1.21

Means followed by the same letter within a column are not significantly different at a 5% probability level according to Duncan's multiple range tests, CD = critical difference, SEM = standard error of the mean, and CV = coefficient of variation.

Table 4: Interaction effect of the irrigation interval and N rate on growth parameters of onion.

Treatment Irrigation interval (day)	N (kg·ha^{-1})	Plant height (cm)	Number of leaves per plant	Leaf length (cm)	Days to maturity
3	0	54.87[fg]	10.47[e]	44.06	95.00[d]
	50	59.73[cd]	11.26[d]	48.40	98.00[c]
	100	62.28[bc]	13.16[a]	50.06	104.66[a]
	150	66.13[a]	13.40[a]	54.06	106.33[a]
6	0	56.53[ef]	10.43[e]	46.27	94.66[d]
	50	58.53[de]	12.10[c]	47.53	96.33[cd]
	100	61.76[bc]	12.66[b]	51.80	102.00[b]
	150	64.20[ab]	12.33[b]	52.70	104.67[a]
9	0	51.46[hi]	8.00[g]	44.20	85.66[e]
	50	53.93[gh]	9.03[f]	45.70	90.00[e]
	100	55.90[fg]	9.25[f]	48.46	90.67[e]
	150	57.00[ef]	9.40[f]	49.31	91.33[e]
12	0	43.80[l]	5.60[l]	37.20	81.66[h]
	50	49.20[l]	6.56[h]	41.60	84.88[g]
	100	51.76[h]	6.48[h]	45.33	85.33[fg]
	150	52.36[h]	6.56[h]	46.53	86.66[f]
CD (<0.05)		0.99	0.18	NS	0.78
SEM (±)		1.88	0.06	2.23	1.11
CV (%)		2.44	2.58	3.16	1.15

Means followed by the same letter within a column are not significantly different at a 5% probability level according to Duncan's multiple range tests, CD = critical difference, SEM = standard error of the mean, CV = coefficient of variation, and NS = nonsignificant.

the mean bulb diameter and weight were significantly higher under 6 and 9 days irrigation intervals than 9 and 12 days. Further, Ayza and Ayana [19] obtained the highest bulb weight (69.4–70.5 g) from the irrigation at a higher level of 100% ETc with 3 and 5 days irrigation intervals at Arba Minch, southern Ethiopia. The increased bulb length with a higher irrigation level of 100% ETc compared to deficit irrigation of 50% ETc has also been reported by Gebregwergis [44] at Algae, Haramaya, Ethiopia. The increase in bulb size and weight under shorter irrigation interval was, obviously, due to increased photosynthesis and assimilation available for the growth and development of bulbs.

The bulb length, diameter, and weight increased significantly with an increase in each successive N rate (Table 5); the overall increases from 0 to 150 kg·N·ha^{-1} being 40, 27, and 30 percent, respectively. A number of workers, similarly, have reported significant improvement in yield components of onion with increased N rates. For instance, Mozumder et al. [46] have reported the bulb length (4.49 cm) and bulb diameter (3.85 cm) to be significantly increased with the increase of N up to 125 kg·ha^{-1}, in the hilly region of Bangladesh. An increase in bulb diameter by about 12 and 16% due to application of 138 and 150 kg·N·ha^{-1} over control has been reported by Abdissa et al. [23] on vertisol of Shewa Robit, Ethiopia and by Kiros and

Table 5: Main effects of the irrigation interval and nitrogen rate on yield and yield components of onion.

Treatment	Bulb length (cm)	Bulb diameter (cm)	Average bulb weight (g)	Total biomass (t ha^{-1})	Unmarketable bulb yield (t ha^{-1})	Marketable bulb yield (t ha^{-1})	Total bulb yield (t ha^{-1})	Harvest index (%)
Irrigation interval (days)								
3	6.33a	6.33a	73.45a	37.32a	2.88a	29.55a	32.44a	86.12a
6	5.91b	6.17a	74.22a	36.84a	2.05b	30.08a	32.14a	86.16a
9	5.45c	5.29b	47.57b	30.86b	2.42b	23.27b	25.69b	81.93b
12	4.84d	4.67c	37.37c	27.61c	2.84a	19.16c	22.01c	78.54b
CD(<0.05)	0.24	0.17	2.03	0.65	0.17	1.32	1.54	3.84
SEM (±)	0.06	0.06	4.11	0.43	1.74	0.14	2.36	14.80
CV (%)	4.24	3.09	3.48	1.97	14.83	5.16	5.48	4.62
N (kg·ha^{-1})								
0	4.71d	4.81d	49.77d	26.88c	3.12a	19.63c	22.74c	79.99b
50	5.14c	5.57c	56.35c	33.07b	2.65b	25.04b	27.69b	83.25a
100	6.12b	5.96b	61.83b	36.22a	2.13c	28.65a	30.88a	84.95a
150	6.58a	6.12a	64.65a	36.45a	2.31c	28.75a	30.96a	84.56a
CD (<0.05)	0.25	0.11	1.90	0.76	0.25	0.87	0.91	2.13
SEM (±)	0.09	0.02	5.11	0.89	0.11	1.08	1.18	6.36
CV (%)	5.35	2.27	3.88	2.85	13.11	4.07	3.86	3.03

Means followed by the same letter within a column are not significantly different at a 5% probability level according to Duncan's multiple range tests, CD = critical difference, SEM = standard error of mean, and CV = coefficient of variation.

Nigussie at Tahtay Koraro, Ethiopia [24], respectively. The larger bulb diameter with increased N has also been reported by Piri and Naserin [47]. More production of larger bulbs is desirable as it influences positively the marketable yield and gross return. Similarly, increased bulb weight by about 34–42% with N rate of 120 kg·ha^{-1} over control has been reported by Nasreen et al. [48] in a two-year study at Joydebpur, Gazipur, Bangladesh.

The interaction of irrigation interval and N rates indicated bulb diameter to be maximum and statistically similar with treatments having 3-day irrigation interval combined with 150 and 100 kg·N·ha^{-1} (6.18 cm, 6.83 cm) and significantly lower with 12-day irrigation interval with no fertilizer (3.66 cm) (Table 6). The bulb weight was statistically similar (78.5–82.0 g) and significantly higher under treatments combining irrigation intervals of 3 and 6 days with 100 and 150 kg·N·ha^{-1}. This implied that the irrigation at 6-day interval combined with 100 kg·N·ha^{-1} was as good as irrigation at 3 days interval with 150 kg·N·ha^{-1} in effecting bulb weight. The least average bulb weight (31.57 g) was obtained at 12 days irrigation interval with no fertilizer N. Similar to our findings, Tsegaye et al. [49] have found a significantly higher bulb diameter (6.16 cm) and bulb weight (106.3 g) with a combination of irrigation at 75% ETc and N rate of 100 kg·ha^{-1} at Hawassa, southern Ethiopia.

In general, the values of yield components of onions tended to increase with increased irrigation frequency and N rate. The higher irrigation frequency and N levels increased the photosynthetic area of the plant (taller plants with a higher number of leaves), resulting in more synthesis and transportation of assimilation of the bulbs.

3.3. Effect of the Irrigation Interval and N Rate on Yield Parameters of Onion. The total biomass, marketable yield, total bulb yield, and harvest index (Table 5) were statistically similar with 3 and 6 days irrigation intervals, but significantly higher with them compared to 9 and 12 days irrigation intervals; the increases being 33, 57, 46 and 10 percent, respectively, under 6 days interval compared to 12 days interval. The lowest yields were obtained with 12 days irrigation interval. The unmarketable bulb yield, however, did not show any consistent trend. Similar to the present results, Ayza and Ayana [19] obtained the highest marketable bulb yield in treatment receiving frequent irrigation at 3 and 5 days interval with a higher level of irrigation (100% ETc) at Arba Minch, Ethiopia. The more frequent irrigation interval of 3 days has also been reported to be producing significantly higher bulb yield than 5, 7, and 9 days irrigation intervals at Bunza, Kebbi State, Nigeria [33]. Further, Patel and Rajput [50] reported that full irrigation (100% crop water requirement) at all stages of plant growth gave the highest marketable yield of 44.7 t·ha^{-1} in New Delhi, India. The enhanced onion productivity was linked to the production of the increased photosynthetic area and dry matter production in response to better moisture availability. Similarly, an increase in irrigation level, as indicated in IW/CPE ratios of 0.60, 0.80, 1.0, and 1.2, had a significant effect on the yield of onion [35]. The best yields were recorded from IW/CPE ratios of 1.0 and 1.2.

The N fertilization had a significant response on yield parameters (Table 5). The higher N rates of 100 and 150 kg ha^{-1}, producing statistically similar yields, gave significantly higher total biomass, marketable yield, and total bulb yield compared to lower rates. The increases in biomass, marketable, and total bulb yields were 35, 46, and 36 percent, respectively, with N rate of 100 kg ha^{-1} compared to no fertilization. The results corroborated with the findings of Kiros and Nigussie [24] who obtained a significant effect of N application on marketable, total biomass, and total bulb yields up to 100 kg·ha^{-1} at Tahtay Koraro, Ethiopia. Further,

Table 6: Interaction effect of the irrigation interval and N rate on yield and yield components of onion.

Treatment		Bulb length (cm)	Bulb diameter (cm)	Average bulb weight (g)	Total biomass (t ha^{-1})	Marketable bulb yield (t ha^{-1})	Unmarketable bulb yield (t ha^{-1})	Total bulb yield (t ha^{-1})	Harvest index (%)
Irrigation interval (day)	*N (kg·ha^{-1})*								
3	0	5.13	5.51^{de}	62.13^{c}	29.35^{f}	21.54^{d}	3.56	25.10^{d}	82.65
	50	5.71	6.17^{c}	70.6^{b}	36.48^{b}	28.86^{b}	2.78	31.65^{b}	86.75
	100	7.02	6.18^{a}	79.6^{a}	41.59^{a}	33.70^{a}	2.57	36.27^{a}	87.22
	150	7.48	6.83^{a}	82.00^{a}	41.84^{a}	34.12^{a}	2.63	36.75^{a}	87.87
6	0	5.11	5.54^{dc}	64.53^{c}	29.72^{f}	23.23^{d}	2.43	25.67^{d}	82.19
	50	5.27	6.13^{c}	73.10^{b}	36.64^{b}	30.31^{b}	2.01	32.33^{b}	88.20
	100	6.27	6.44^{b}	78.47^{a}	40.31^{a}	33.56^{a}	1.76	35.34^{a}	87.66
	150	7.01	6.58^{ab}	80.76^{a}	40.69^{a}	33.20^{a}	2.02	35.22^{a}	86.58
9	0	4.57	4.54^{g}	40.86^{g}	26.12^{h}	18.61^{e}	3.29	21.90^{e}	78.43
	50	5.11	5.37^{e}	46.23^{ef}	31.52^{de}	22.61^{d}	2.52	25.13^{d}	79.73
	100	5.83	5.58^{ed}	49.86^{ed}	33.27^{c}	25.99^{c}	1.77	27.76^{c}	83.40
	150	6.28	5.66^{d}	53.10^{d}	32.54^{cd}	25.87^{c}	2.13	28.00^{c}	86.15
12	0	4.04	3.66^{h}	31.57^{i}	22.34^{i}	15.14^{f}	3.18	18.32^{f}	76.68
	50	4.45	4.62^{g}	35.46^{hi}	27.65^{g}	18.37^{e}	3.29	21.67^{e}	78.34
	100	5.34	5.03^{f}	39.93^{gh}	29.69^{f}	21.72^{d}	2.45	24.17^{d}	81.52
	150	5.53	5.38^{e}	42.53^{fg}	30.54^{ef}	21.43^{d}	2.46	23.89^{d}	77.64
CD (<0.05)		NS	0.09	1.6	0.65	0.79	NS	0.85	NS
SEM (±)		0.08	0.02	4.91	0.80	1.21	0.12	1.41	8.05
CV (%)		5.15	2.45	3.81	2.69	4.32	13.48	4.24	3.41

Means followed by the same letter within a column are not significantly different at a 5% probability level according to Duncan's multiple range tests, CD = critical difference, SEM = standard error of mean, CV = coefficient of variation, and NS = nonsignificant.

Table 7: Simple coefficients of correlation between plant growth, yield, and yield components of onion.

Variable	PH	NL	DM	LL	BL	BD	ABW	TBM	MBY	UMBY	TBY	HI
PH	1											
NL	0.929**	1										
DM	0.946**	0.962**	1									
LL	0.912**	0.797**	0.826**	1								
BL	0.864**	0.736**	0.826**	0.856**	1							
BD	0.945**	0.904**	0.931**	0.894**	0.864**	1						
ABW	0.932**	0.967**	0.968**	0.792**	0.776**	0.910**	1					
TBM	0.926**	0.886**	0.920**	0.867**	0.869**	0.963**	0.886**	1				
MBY	0.929**	0.911**	0.932**	0.868**	0.872**	0.952**	0.919**	0.979**	1			
UMBY	−0.415**	−0.376**	−0.351*	−0.530**	−0.458**	−0.491**	−0.376*	−0.507**	−0.535**	1		
TBY	0.933**	0.919**	0.944**	0.858**	0.869**	0.950**	0.928**	0.977**	0.996**	−0.459**	1	
HI	0.752**	0.750**	0.741**	0.686**	0.703**	0.742**	0.778**	0.734**	0.822**	−0.289	0.835**	1

**Correlation is significant at the 0.01 level (2-tailed). *Correlation is significant at the 0.05 level (2-tailed). PH = plant height; NL = leaf number; DM = days of maturity; LL = leaf length; BL = bulb length; BD = bulb diameter; ABW = average bulb weight; TBM = total dry biomass; MBY = marketable bulb yield; UMBY = unmarketable bulb yield; TBY = total bulb yield; HI = harvest index.

Abdissa et al. [23] obtained increased total dry biomass by 20%, total bulb yield by 18%, and marketable bulb yield by 17% with the application of 69 kg·N·ha^{-1}over the control on vertisols of Shewa Robit, northeast Ethiopia. The higher N rates of 100 and 150 kg·ha^{-1} also gave a significantly less low-quality unmarketable yield of onions (Table 5), as also shown by Tekle [42] in the central zone of Tigray and Kiros and Nigussie [24] in Tahtay Koraro, Ethiopia. The N fertilization also improved significantly the harvest index of onions (85%), showing an increase of 6% over control with N rate of 100 kg·ha^{-1} (Table 5). Likewise, the higher harvest index (83%) with an increased N rate to 100 kg·ha^{-1} (showing an increase of 22% over control) has been reported by Tsegaye et al. [49] at Hawassa, southern Ethiopia.

As for the interaction effect of irrigation interval and N rate (Table 6), the 3 and 6 days irrigation intervals combined with 100 and 150 kg·N·ha^{-1} produced statistically similar biomass yield (40.3–41.8 t·ha^{-1}), marketable yield (33.2–34.1 t·ha^{-1}), and total bulb yield (35.2–36.7 t·ha^{-1}), which were, in turn, significantly higher than yields from rest of the combinations. The 12 day irrigation interval combined with no fertilization produced significantly lower biomass yield (22.3 t·ha^{-1}), marketable yield (15.1 t·ha^{-1}), and total bulb yield (18.30 t·ha^{-1}) than the rest of the treatment combinations. Accordingly, the increases in biomass, marketable, and total bulb yields under shorter irrigation intervals of 3 and 6 days combined with 100 and 150 kg·N·ha^{-1} were 81–87, 120–126, and 92–100 percent, respectively, compared to longer irrigation interval of 12 days with no fertilization. Similar to our results, Geberegwergis [44] obtained the highest marketable bulb yield of 35.62 t·ha^{-1} with a higher level of irrigation (100% ETc) combined with 138 kg·N·ha^{-1}.

Table 8: Partial budget analysis in respect of irrigation and fertilizer N levels on marketable yield of onion.

Treatment combination	Unadjusted marketable yield (t ha^{-1})	Adjusted marketable yield (t ha^{-1})	Gross benefit (Birr ha^{-1})	Total variable cost (Birr ha^{-1})	Net benefit (Birr ha^{-1})	Cost dominance
Ir4*N0	15.14	13.63	163512	57872	105640	
Ir4*N1	16.51	14.86	178308	58527	119781	
Ir4*N2	18.21	16.39	196668	59182	137486	
Ir4*N3	17.92	16.13	193536	59837	133699	D
Ir3*N0	18.60	16.74	200880	64872	136008	D
Ir3*N1	22.61	20.35	244188	65260	178928	
Ir3*N2	25.99	23.39	280692	66182	214510	
Ir3*N3	25.87	23.28	279396	66837	212559	D
Ir2*N0	23.23	20.91	250884	72872	178012	D
Ir2*N1	28.31	25.48	305748	73527	232221	
Ir2*N2	33.57	30.21	362640	74182	288458	
Ir2*N3	33.20	29.88	358560	74834	283726	D
Ir1*N0	21.54	19.39	232632	105872	126760	D
Ir1*N1	28.86	25.97	311688	106527	205161	D
Ir1*N2	33.70	30.33	363960	107182	256778	D
Ir1*N3	34.12	30.71	368496	107837	260659	D

Ir1 = 3 days irrigation interval; Ir2 = 6 days irrigation interval; Ir3 = 9 days irrigation interval; Ir4 = 12 days irrigation interval; N0 = no nitrogen fertilizer; $N1$ = 50 kg nitrogen; $N2$ = 100 kg nitrogen; $N3$ = 150 kg nitrogen; D = dominated.

Table 9: Marginal rate of return (MRR) in respect of irrigation and fertilizer N levels on marketable yield of onion.

Treatment combination	Total variable cost (Birr ha^{-1})	Net benefit (Birr ha^{-1})	Marginal rate of return (%)	Rank
Ir4*N1	58527	119781	2159	D
Ir4*N2	59182	137486	2703	C
Ir3*N1	65260	178928	682	E
Ir3*N2	66182	214510	3859	B
Ir2*N1	73527	232221	241	F
Ir2*N2	74182	288458	8586	A

Ir2 = 6 days irrigation interval; Ir3 = 9 days irrigation interval; Ir4 = 12 days irrigation interval; $N1$ = 50 kg nitrogen; $N2$ = 100 kg nitrogen.

The marked increase in yield of onions in response to the frequent irrigation and higher N rates could be due to enhancement of growth and, thereby, production of assimilates and their partitioning to the bulbs. This was quite evident from the significant positive relationships ("r" values) between growth parameters, yield components, and final yields of onions (Table 7). For instance, the plant height indicated significant positive correlation values of 0.864**, 0.945**, 0.932**, 0.926**, 0.929**, and 0.933** with bulb length, bulb diameter, bulb weight, total biomass, marketable bulb yield, and total bulb yield, respectively. Similarly, yield components like bulb length, bulb diameter, and total bulb weight showed a significant positive relationship with total biomass, marketable bulb yield, and total bulb yield. Testifying our findings, the results of a large number of studies on plant-based water stress indicators, reflecting the growth and development of plants, were consistent with the final yields of crops [51].

3.4. Economic Analysis. The economic analysis was made following the procedure of CIMMYT [32]. As required by the procedure, the average yield of 16 treatments was adjusted downwards by 10% (Table 8), as yields from the experimental plots are supposed to be higher than farmers' fields. The total costs and net benefits were calculated for different combinations. To obtain the gross benefit, the adjusted yield was multiplied by the field price of onions (12 birr·kg^{-1}) at the time of harvest. The variable cost of different treatments included labour cost (80 birr per day per person) of irrigation and fertilizer application and the cost of fertilizer urea. The price of fertilizer N was 13.1 birr·kg^{-1}. The variable cost was subtracted from gross benefit to obtain net benefit. The highest net benefit of Birr 288,458 ha^{-1} was recorded from the combination of 6 day irrigation interval and 100 kg·N·ha^{-1}. The marginal rate of return (MRR) was also higher (8586%) for the combination of 6 day irrigation interval and 100 kg·N·ha^{-1} (Table 9).

4. Conclusion

The irrigation at 6 days interval combined with 100 kg·N·ha^{-1} gave a higher marketable bulb yield (30.2 t·ha^{-1}), net return (Birr 288,458 ha^{-1}), and marginal rate of return (8586%). As such, irrigation equivalent to ETc at an interval of 6 days and N at the rate of 100 kg·ha^{-1} may be recommended for higher productivity and profitability of onion (Bombay Red variety) at Arba Minch, southern Ethiopia. The findings may be refined further by taking up multiseason data and employing locally determined parameters of crop coefficient (Kc) and crop water requirement (ETc). Also, the studies may be taken up to find an optimum N rate for the crop under rainfed conditions.

Data Availability

The data used to support this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this paper.

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