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Determination of Optimum Irrigation Scheduling for Onion (*Allium Cepa* L.) at Bena Tsemay District, Southern Ethiopia

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Abstract: The effective use of irrigation methods is crucial for increasing crop productivity and promoting the sustainable use of agricultural land. Therefore, increasing agricultural water productivity is one of the most important ways to counteract future water scarcity. A field experiment was conducted to determine the optimal irrigation regime for onion cultivation in Bena Tsemay district for two consecutive years. The experiment was laid out in a randomized complete block design with five irrigation treatments and four replications. The treatments included five levels of irrigation regimes: 60%, 80%, 100%, 120% and 140% available soil moisture depletion levels. The results showed that irrigation regimes had a significant effect on plant height, bulb diameter, marketable yield and total yield, with a p-value of less than 0.05. The highest marketable yield (30.72 kg/ha) was observed at 100%ASMDL, followed by (30.49 kg/ha) at 80%ASMDL. However, irrigation at 140%ASMDL resulted in the lowest yields of both marketable and total onion. The two-year combined analysis revealed that the highest (6.5 kg/m^3) water productivity was recoreded at 100% ASMDL, followed by (6.45 kg/m^3) at 80% ASMDL. In contrast, the lowest water productivity (3.21 kg/m^3) was recorded at 140% ASMDL. Therefore, based on the results of the current trial, it is recommended that the use of 80% ASMDL for a furrow irrigation system, and in similar agro ecology is a crucial option to increase the yield and water productivity of onion.

Keywords; Irrigation scheduling, onion yield, soil moisture deplition, water productivity.

Introduction

Irrigation development in Ethiopia has the potential to improve farm production, income, asset endowment, and employment opportunities while improving household poverty rates and reducing the nation's susceptibility to climate unpredictability (Ambachew & Sintayehu, 2020). According to several reports, Ethiopia is currently planning to use its water resources to cultivate, develop, and irrigate numerous hectares of land in low-lying regions of the nation to combat poverty and provide food security. Furthermore, to solve the problem of water scarcity and achieve food self-sufficiency, the Ethiopian government has given priority to agricultural growth through the promotion of small-scale irrigation (Yohannes, 2020).

In Ethiopia's semi-arid and desert regions, the primary obstacles to agricultural growth include inadequate infrastructure and market institutions, a scarcity of technology and inputs, and a high degree of rainfall variability (Bekabil, 2014). Bena Tsemay is among the districts in Ethiopia that experience a continuous drought and water scarcity due to infrequent and poor rainfall, causing frequent disruptions to agricultural productivity. As a result, there was rivalry among the locals for the use of water for crop and livestock development. Nevertheless, a major obstacle to increasing agricultural output in the area and utilizing irrigation water efficiently is the lack of more sophisticated small-scale irrigation technologies, irrigation water management plans, and research funding.

The availability of water for irrigated agriculture declined as a result of depleting water supplies, intensifying competition for water, and inadequate on-farm irrigation management practices throughout crop production (Ayana, 2011). This put the food supply at risk and exacerbated rural poverty. Enhancing agricultural water management techniques is essential to preserving food security worldwide and reducing rural poverty (Mengiste., 2015). Therefore, increasing water use efficiency would be the research area's main task going forward. This is known as applying appropriate methods and strategies that provide crops with a more precise supply of water in the appropriate quantity at the appropriate time. Therefore, the purpose of this study was to determine the response of the optimum irrigation regime on the yield and water productivity of onion in the study area.

Materials And Methods

Description of the study area

The investigation was carried out at the experimental site of the Jinka Agricultural Research Center in Bena Tsemay District (Fig. 1). Geographically, the experimental site is located at an elevation of 550 meters above sea level and between 5°18′0″ to 5°31′33″ N latitude and 36°52′30″ to 37°5′0″ E longitude as stated by (Mugoro et al., 2021). The site is 438 km south of Hawassa, 668 km southwest of Addis Ababa, Ethiopia, and 82 km from Jinka town.

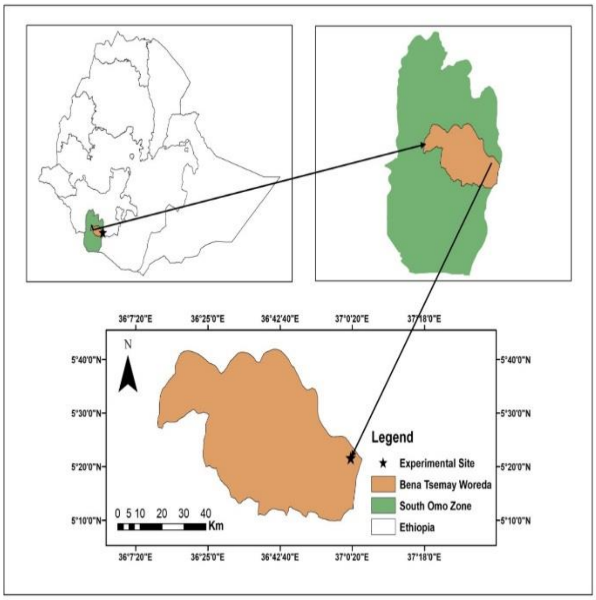

Fig. 1 Map of the study area.

Physicochemical properties of soil

Samples of soil were collected from the experimental field at depths of 0–20, 20–40, and 40–60 cm. Soil textural class was analyzed by using the hydrometer method for undisturbed soil samples for each depth. The hydrometer method was used to analyze the particle size distribution and the structural class was determined based on the percentage of sand, silt and clay in the structural triangle as stated by (Sedaghat et al., 2016). The bulk density of the soil was determined from undisturbed soil samples using a core drill with an internal diameter of 5 cm. The soil sample was oven-dried for 24 hours at a temperature of 105°C to remove the soil moisture. According to (Mugoro et al., 2021), the bulk density was computed as the ratio of the soil's dry weight to the known cylindrical core sampler volume.

The moisture content of the soil was carried out by taking the collected soil samples under an oven at a temperature of 105°C for 24 hours. The dry soil was taken out of the oven; cooled and weighed again. Then, the dry weight was recorded and moisture content was calculated using the procedure of (Narayanan, 2001). The soil's pH, electrical conductivity (EC), organic carbon (OC), and organic matter (OM) content were among the chemical characteristics that were investigated. The electrical conductivity (EC) and pH of the soil were measured using electrical conductivity meters and pH meters in accordance to (Sedaghat et al., 2016). The organic carbon was evaluated using a colorimetric approach. The amount of organic matter (OM) was calculated by multiplying the organic carbon (OC) by a constant factor of 1.724 as stated by (Sleutel et al., 2007). According to Sleutel et al., (2007), the amount of organic matter (OM) was determined by multiplying the organic carbon (OC) by a constant factor of 1.724.

Experimental design and procedure

The experiment was carried out using a Randomized Complete Block Design (RCBD) with four replications over the course of two years, from 2021 to 2022. Using the (Doorenbos et al., 1980)**,** soil moisture depletion values as a guide, five irrigation treatments were chosen, with the levels of 60%, 80%, 100%, 120%, and 140% being the available soil moisture depletion levels (ASMDL). The proportion of soil water that was accessible in the root zone was used to determine when to water. The water requirement for the cultivation of onion bulb was determined for each growth stage using the CROPWAT program.

Bombay Red onion seeds were sown on well-prepared 1 m with a 5 m seedbed. The Bombay Red is an onion variety (Allium cepa L.) that matures early and has a high yield stated by (Olani & Fikre, 2010)**.** Before transplanting, the seedling management strategy was implemented in accordance with the area's recommendations. After that, the seedling was placed at a row and plant spacing of 40 and 5cm, respectively, in carefully prepared experimental plots on either side of a ridge.

The experimental field was divided into 16 plots, each of which had a dimension of 3.6m by 3m. To guarantee plant establishment, two common irrigations were given to onion seedlings that were transplanted to the experimental field. Fertilizer application was used as recommendation made for the area as stated (Tesema et al., 2021), while urea was split into two applications, one at the time of transplanting and the other 10 days later at rates of 200 kg/ha and 100 kg/ha, respectively, according to finding of (Olani & Fikre, 2010).

Crop and irrigation water requirements

Based on the daily meteorological data collected from the study site, the CropWat software program version 8.0 was used to compute the daily evapotranspiration. Root depth, crop coefficient, and ideal depletion level were taken from FAO Irrigation and Drainage Paper 56 (Allen et al., 1998). Daily CropWat model calculations were used to determine the effective rainfall during the growing season based on dependable rainfall. The amount of moisture in the soil was measured using the gravimetric method.

Using a field application efficiency of 60%, the gross irrigation requirement was calculated. The short end-diked furrow irrigation practice with an application efficiency of 60% was utilized to calculate the gross irrigation requirement during this trial according to (Brouwer et al., 1989). The amount of water applied using the furrow irrigation method was measured using a 3-inch Parshall flume, which has a corresponding head and discharge rate.

Data Collection

The physical properties of the soil, including bulky density, permanent wilting point, texture, and field capacity, were gathered and determined. Data on vegetative growth, yield, and yield components were recorded from five randomly selected plants in each experimental plot, according to finding (David, 2014).

Crop Water Productivity

The water productivity of plants is the yield in kilograms per total water used. Water productivity, according to (Zwart, 2010), was calculated as the harvested yield divided by the total amount of water consumed.

$$\mathrm{WP} = \frac{\mathrm{Y}}{\mathrm{ET}}$$

Where, WP is water productivity (kg/m^3), Y yield (kg/ha) and ETc is the seasonal crop water consumption by evapotranspiration (m^3/ha).

Statistical Analysis

The collected data was subjected to ANOVA by using R statistical software (version 4.1.3) for Windows based on randomized complete block design. Treatment means were compared using the least significant difference (LSD at $p = 0.05$) if the treatment effects were found to be statistically significant stated by (Steel & Torrie, 1996).

Results and Discussion

Soil Physical Properties

The soil particle size distribution at the experimental site is shown in Table 1. The laboratory analysis revealed that the soil of the experimental field has a uniform texture with an average composition of sand, silt, and clay content of 41.5%, 24.9%, and 33.6%, respectively according to (Lebiso & Mada, 2022). As a result, the soil of the experimental field was classified as loam in texture by the USDA. Loam soils are ideal for growing onion because they contain desirable characteristics of sand, silt, and clay stated (Olani & Fikre, 2010).

Table 1 Particle size distribution of the experimental site.

	Particle size distribution (%)			Textural class
	Sand	Clay	Silt	
0 – 20	40.8	27.2	32.0	Loam
20 – 40	38.0	24.0	38.0	Loam
40 – 60	45.6	23.6	30.8	Loam
Average	41.5	24.9	33.6	Loam

Note: USDA Soil classification

The bulk density and available total water content at FC and PWP values are shown in Table 2. The average bulk density of the soil from the test site showed a slight variation with depth. It varied between 1.26 g/cm3 in the upper root zone (0 – 20 cm) and 1.31 g/cm^3 in the lower root layer (40 – 60 cm). The bulk density shows a slight increase with depth, which can be attributed to the slight increase in soil compaction with depth due to the weight of the overlying soil layer stated (Tsehai, 2016). The bulk density of the soil was 1.28 g/cm3, which was in a range suitable for plant growth according to (Umare, 2018). The total available water-holding capacity (TAW) of the soil was computed by utilizing the field capacity and permanent wilting point of the soil. The permanent wilting point and the average field capacity of the soil were measured at 27.83% and 11.99%, respectively. Due to this, the onion roots reached a depth of 60 cm, and the TAW in the trial site was 95.04 mm. The basic infiltration rate of the soil was approximately 27.3 mm/h, which is typical for loam soils according to (Brouwer & Heibloem, 1986).

Table 2 The physical characteristics of the experimental site's soil.

Depth (cm)	BD (g/cm^3)	FC (%vol.)	PWP (%vol.)	TAW (mm)
0 – 20	1.26	29.31	12.78	33.06
20 – 40	1.28	28.13	12.46	31.34
40 – 60	1.31	26.04	10.72	30.64
Average	1.28	27.83	11.99	31.68
Total available water in 60 cm				95.04

Note: PWP is for permanent wilting point; TAW stands for total available water; BD stands for bulk density; and FC for field capacity.

The Chemical Properties Of Soil

The average pH of the trial location was determined to be 7.83 shown in Table 3, almost alkaline (Lebiso & Mada, 2022). The result of pH of study area soil was within the acceptable range for onions, as stated by (Olani & Fikre, 2010). The average electrical conductivity of the soil through a 60 cm soil profile was determined to be 0.182 dS/m, which was lower than the 1.2 dS/m threshold value for yield loss (Smith et al., 2011). The soil had an average OM and OC content of 2.67% and 1.55%, respectively, indicating high soil fertility and suitability for vegetable cultivation, as stated by (Sedaghat et al., 2016).

Table 3 Soil chemical properties of the experimental site.

Depth (cm)	pH	ECe (dS/m)	OC (%)	OM (%)
0 – 20	7.69	0.210	1.43	2.46
20 – 40	7.93	0.173	1.65	2.85
40 – 60	7.87	0.178	1.58	2.72
Average	7.83	0.182	1.55	2.67

Note: ECe - Electrical conductivity of soil, OC - organic carbon, OM - organic matter

Irrigation Water Requirement of Onion

The amount of water used for seasonal irrigation changed depending on the onion's growth stage was shown in Table 4. Accordingly, the water depth applied increased from the initial stage to the mid-stage and then decreased at the late stage. The highest irrigation requirement (167.02 mm) was observed in the middle phase, while the lowest (72.38 mm) was observed in the initial phase. The results determined that the mid-stage onion attained its maximum irrigation water depth; this was due to the high ET_o and the high crop coefficient as stated by (Allen et al., 1998). Similarly, the finding of (Pérez & Knox, 2015) confirmed that the variation in seasonal water requirement was due to agroclimate, location, and crop coefficient values. The research site's seasonal net irrigation requirement for onion was 472.96 mm, falling within the recommended range for onion according to (Zwart, 2010).

Table 4 The seasonal amount of irrigation water applied.

Growing Stage	Growing date (day)	ETc (mm/d)	NIR depth (mm)	GIR depth (mm)
Initial	20	3.62	72.38	120.63
Development	30	4.69	140.72	234.54
Mid	30	5.57	167.02	278.37
Late	20	4.64	92.83	154.71
Total	100		472.96	788.26

Where: ETc- crop evapotranspiration,NIR and GIR- net and gross irrigation requirement

Based on the degree of soil moisture depletion, the amount and frequency of irrigation were monitored in the field was presented in Table 5. The amount of soil moisture lost determined the rate at which water was applied. The irrigation treatments were set at 3, 4, 5, 6, and 7-day intervals based on the soil moisture content of the field. The corresponding net irrigation depths were 14.26, 19.01, 23.76, 28.51, and 33.26 mm, respectively. It was observed from the results that onions need light and frequent irrigations during the growth stages, similarly, the result agrees with (Yaziz, 2019). Since there was no rainfall during the experimental season, the net irrigation depth was regarded as readily available water for the onion crop.

Table 5 Irrigations frequency, Eff. RF and net irrigation depth applied.

Treatment	Irrigation frequency	Eff. RF(mm)	RAW(mm)
60%ASMDL	3	0	14.26
80%ASMDL	4	0	19.01
100%ASMDL	5	0	23.76
120%ASMDL	6	0	28.51
140%ASMDL	7	0	33.26

Where: Eff. RF- Effective rain fall, RAW- readily available water

Response of optimal irrigation on yield and water productivity of onion

Regarding yield and yield components, there were significant variations ($P < 0.05$) between the applied soil moisture depletion levels. The analysis of variation for plant height, bulb diameter, marketable yield, nonmarketable yield, and total bulb yield of onion in Table 6. The treatment at 60% of the available soil moisture depletion level (ASMDL) produced the maximum plant height during a two-year period, whereas the treatment at 140% of ASMDL produced the lowest. The study suggests that plant height increases when onion irrigated with a short irrigation interval. The shortest irrigation interval is important for increasing onion vegetative growth rather than yield and bulb diameter (Muche & Fentahun, 2022). Similar report of (Wakchaure et al., 2018), stated that frequent irrigation increased total yield and plant growth characteristics while decreasing bulb diameter and marketable yield.

The study found that the largest bulb diameter was observed at 140% ASMDL, while the smallest was at 60% ASMDL. The longest interval between irrigations resulted in the greatest bulb diameter. Additionally, the depletion of soil moisture levels led to a significant increase in bulb diameter. The highest yield of marketable onion, 30.72 t/ha and 30.49 t/ha, were achieved with irrigation at 100% and 80% ASMDL, respectively. However, irrigation at 140% ASMDL resulted in the lowest yields of both marketable and total onion.

The lowest yield of nonmarketable onion was obtained with an irrigation application of 80 %ASMDL and shows no significant difference compared to an irrigation application of 100 %ASMDL. The highest unsaleable onion yield of 1.22 t/ha was obtained with 140%ASMDL irrigation, with no significant difference compared to 120%ASMDL irrigation. The study showed that the yield and yield components of onion influenced by the irrigation regime (Table 6). The result of study indicated that onion yield was depends on the frequency and depth of irrigation water applied. This agrees with (Kadayifci et al., 2005) stated that onion yield strongly depended on the amount of water and the timing of irrigation. Similarly, the finding of (Mermoud et al., 2005), reported that irrigation frequency has a major influence on onion crop yield.

Table 6 Effect of irrigation scheduling on plant height, yield components and water use efficiency of onion.

Treatments	Plant height (cm)	Bulb diameter (cm)	Marketable bulb yield (t/ha)	Nonmarketable bulb yield (t/ha)	Total bulb Yield (t/ha)
60%ASMD	53.04^{a}	5.01^{d}	22.96^{b}	1.09^{ab}	24.05^{b}
80%ASMDL	52.11^{a}	5.44^{cd}	30.49^{a}	0.73^{c}	31.22^{a}
100%ASMDL	50.96^{a}	5.87^{bc}	30.72^{a}	0.82^{c}	31.54^{a}
120%ASMDL	47.81^{b}	6.05^{ab}	24.61^{b}	0.98^{ab}	25.59^{b}
140%ASMDL	42.59^{c}	6.44^{a}	15.20^{c}	1.22^{a}	16.42^{c}
Mean	49.3	5.76	24.79	0.97	25.76
LSD	2.49	0.48	2.3	0.13	2.3
CV (%)	3.28	5.37	6.01	8.68	5.8

Note: means with the same letter (s) are not significantly different at $P < 0.05$; LSD= least significant difference; CV = Coefficient of variation.

Water Productivity

Water productivity was estimated as the ratio between the yield of marketable onion and the total irrigation depth applied during the season (Table 7). The total investigation over the course of two years revealed that the highest water productivity, measured at 100% and 80% of ASMDL, respectively, was 6.5 kg/m^3 and 6.45 kg/m^3. On the other hand, at an application rate of 140%ASMDL, the lowest water productivity of 3.21 kg/ha was noted. The results of the study show that shorter irrigation intervals lead to higher yields and higher water productivity than longer irrigation intervals. These results are consistent with the statement that too long an irrigation interval reduces maize yield and water productivity as the finding of (Zhang et al., 2019).

Table 7 Water productivity for different irrigation treatments of onion.

Treatments	Amount of Water Applied (m^3/ha)	Bulb Yield (kg/ha)	Water Productivity (kg/m^3)
60%ASMD	4729.6	22960	4.85
80%ASMDL	4729.6	30490	6.45
100%ASMDL	4729.6	30720	6.5
120%ASMDL	4729.6	24610	5.2
140%ASMDL	4729.6	15200	3.21

Conclusion

Irrigation schedules are essential and best practice for managing irrigation water and increasing crop productivity. Applied soil moisture had a significant effect ($P < 0.05$) on the analysis of variance of plant height, bulb diameter, marketable yield, nonmarketable yield and total bulb yield. Maximum marketable onion yield was 30.72 kg/ha at 100% ASMDL, followed by 80% ASMDL with 30.49 kg/ha, and no statistical significance found. However, irrigation at 140% ASMDL resulted in the lowest yields of both marketable and total onion bulb yield. The lowest nonmarketable onion bulb yield was obtained at 80% ASMDL, while the highest yield of 1.22 t/ha was obtained at 140% ASMDL. The two-year combined analysis revealed that the maximum water productivity of 6.5 kg/m^3 was recorded at 100% ASMDL followed by 80% ASMDL with 6.45 kg/m^3. On the other hand, the lowest water productivity of 3.21 kg/m^3 was observed at an application rate of 140% ASMDL. The results of the study showed that compared to longer irrigation intervals, shorter irrigation intervals lead to higher yields and higher water productivity. The results show that irrigation with an irrigation interval of four days and readily available water of 19.1 mm at 80% ASMDL resulted in optimal onion yield and water productivity. Based on the results of this trial, it is therefore recommended to grow onion in the study area with a furrow irrigation system at 80% ASMDL.

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