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Research Article

Determination of Optimal Irrigation Scheduling for Onion Under Furrow Irrigation Method in Eastern Hararghe Zone, Ethiopia

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Abstract

Efficient irrigation water management is critical for optimizing crop productivity and ensuring the sustainable use of limited water resources, particularly in semi-arid regions. This study was conducted during the 2022/23 and 2023/24 cropping seasons at Kombolcha District, East Hararghe Zone, Oromia regional state, Ethiopia. The purpose of the activity was to create optimal irrigation regimes (when and how much to irrigate) for onions and evaluate the effect of different irrigation timings on the water productivity and yield of the onion crop. The results showed that irrigation water, maximum irrigation frequency, and short irrigation intervals were achieved by scheduling irrigation at 60% of the ASMDL treatment. The next maximum irrigation frequency was obtained by scheduling irrigation at 80% of ASMDL treatment. Minimum irrigation frequency and minimum water consumed by scheduling irrigation at 140% ASMDL treatment. The results show that the maximum onion yield was obtained by scheduling irrigation at 60% of ASMDL treatment, followed by 80% ASMDL treatment. Statistically, there is no significant difference between 60% ASMDL and 80% ASMDL treatments in terms of onion yield. Maximum water productivity was obtained by scheduling irrigation at 80% ASMD treatment followed by 60% ASMDL treatment. Statistically, there is no significant difference between 60%, 100%, and 120% ASMDL treatments in terms of onion water productivity. The minimum water productivity was reached by scheduling irrigation at 140% ASMDL treatment. So, scheduling irrigation at 80% ASMDL is recommended for onion with 5-day, 6-day, 7-day, and 10-day irrigation intervals at initial, development, mid, and maturity stages of onion, respectively.

Keywords

Irrigation Scheduling, Onion, Water Demand

1. Introduction

The rapid exponential increment of population growth worldwide, in general and in developing countries, is forcing the environment to produce more food and cash crops to feed and enhance the economic development of the people [1]. However, environmental resources, such as land and water, are limited and even decreasing due to overexploitation, pollution, and climate change [2]. Irrigation schedules must be tailored to local environmental circumstances, soil type, and water availability to ensure sustainable use of water resources in agriculture. [3].

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In Ethiopia, although irrigation has long been conducted at different farm levels, there is no efficient and well-managed irrigation water practice [4]. According to the USA Bureau of Reclamation (2005), Irrigation water management is the act of timing and regulating irrigation water applications without the waste of water, soil, and plant nutrients [5]. Consequently, conserving water in irrigation is the most critical issue to be considered [6]. Irrigation water is considered a crucial element for crop production [3, 11]. In Ethiopia, onions are produced in many parts of the country by small farmers, private growers, and state enterprises [7]. In many parts of the country, the off-season crop (irrigated) accounts for a significant portion of onion production [8].

Among vegetable crops, onion is one of the most extensively utilized foods globally [6]. The average world yield grew from 18.4 t/ha in 2004 to 19.2 t/ha in 2018. The top onion-producing countries are China, India, and the United States of America, accounting for 20% of global production [7]. Water requirements for onions vary depending on location and irrigation system [8]. Onions have a maximum root penetration of 76 cm, although the majority of it occurs in the first 18 cm of soil, limiting the amount of soil water available to roots [9]. Rainfall is therefore insufficient to maintain its output, making irrigation essential. To avoid over- or under-irrigation, it is important to know how much water is available to the plant and how efficiently the crop can use it, which means irrigation scheduling [10]. Developing the best irrigation schedules (when and how much to irrigate) for onions and assessing the impact of various irrigation schedules on water productivity and onion crop output were the goals of the work.

2. Methods and Materials

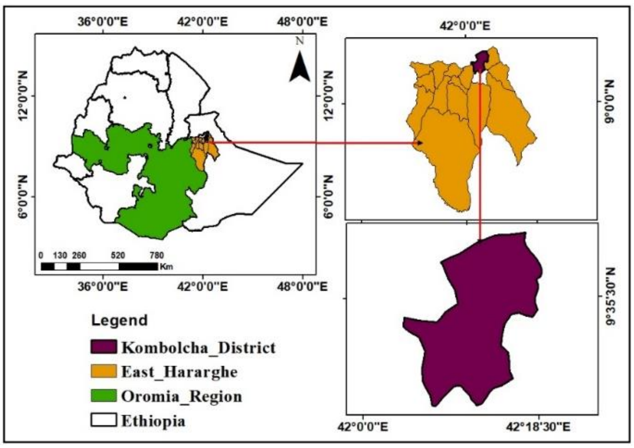

Figure 1. *The Research Area Map.*

2.1. Description of the Experimental Site

The experiment was carried out at KPT College in the Kombolcha district of the Eastern Hararghe zone of Oromia, which is situated at an elevation of 2160 m above sea level and has an irregular and uneven rainfall distribution. The mean minimum and maximum temperatures there are 10 ℃ and 27.8 ℃, respectively. The irrigation water came from manually drilled tube wells.

2.2. Climatic Characteristics

The climatic data, maximum and minimum temperature, relative humidity, Rainfall, wind speed, and sunshine hours every month were collected from the nearby meteorological station. Potential evapotranspiration (ETo) was estimated using the CROPWAT software version 8.

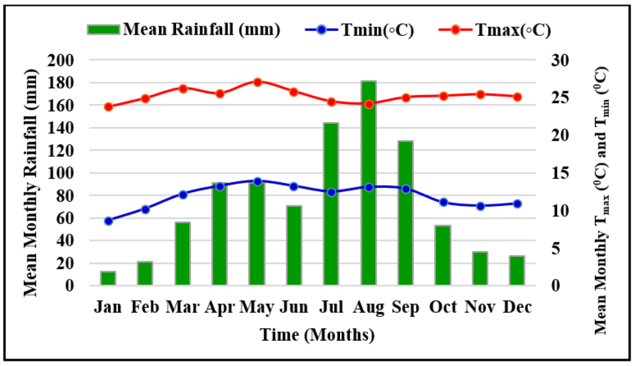

Figure 2. *Long-term mean monthly climatic data of the experimental area (2000 – 2023).*

2.3. Design of the Experiment

Five treatments with three replications made up the Randomized Complete Block Design (RCBD) used in the investigation. Five soil moisture depletion levels (SMDL), which dictate when to water onions, were used in the treatment combination. There were fifteen experimental plots, with two meters separating each plot from the block. The Sifan onion variety was used as a test crop.

Table 1. *Treatment Plan.*

Treatment	Description of Treatment
T1	60% of ASMDL
T2	80% of ASMDL
T3	100% of ASMDL*
T4	120% of ASMDL
T5	140% of ASMDL

2.4. De-estimation of Crop Water Requirement of Onion

Climatic data (rainfall, temperature, wind speed, relative humidity, and sunshine hours) were used for the determination of the water requirement of onion. ETo is computed by the CROPWAT model version 8.0 using the FAO Penman-Monteith approach formula.

2.5. Scheduling Irrigation

Soil water depletion replenishments were used to schedule the irrigation. A digital smart soil moisture meter (Theta probe ML3) and the gravimetric method were used to measure the soil water content both before and after full irrigation in order to keep it between the field capacity and the permitted depletion level.

2.6. Calculating the Net Water Need for Irrigation

The equation, In = ETc - PE (1)

The following equation was used to calculate effective rainfall: Peff = 0.6 * P - 10 for precipitation less than or equal to 70 mm, Peff = 0.8 * P - 24 for precipitation greater than 70 mm, where Peff is the effective precipitation (mm) and P is the precipitation (mm). In-Net Irrigation Depth (mm), ETc is the crop water requirement (mm), and Pe is the effective rainfall (mm).

2.7. Total Depth of Irrigation

60% was considered to be the irrigation efficiency, which is typical for surface irrigation techniques in furrow irrigation. [13]. The gross irrigation water need was computed as follows using the net irrigation depth and irrigation application efficiency:

$$Ig = \frac{\text{In}}{\text{Ea}} \tag{2}$$

Where: Ea - Furrow Application Efficiency (%), In - Net Irrigation Depth (mm), and Ig - Gross Irrigation Depth (mm).

The ratio of the applied water volume to the discharge-head relation of 3-inch PF was used to determine how long each treatment would take to irrigate. An equation provided by was used to determine the amount of time needed to supply the correct depth of water into each furrow.

$$T = \frac{\text{Ig}*\text{W}*\text{L}}{6\text{Q}} \tag{3}$$

Where: W is the plot's space of furrow (m), L is its length (m), Q is its flow rate (l/s), and Ig is the gross depth of water applied (cm).

2.8. Productivity of Water

Crop yield per unit volume of water supplied to the crops is known as water productivity [12]. The ratio of onion production to the total irrigation depth used during the season was used in this study to determine agricultural water productivity. It is stated as:

$$Wp = \frac{\text{Y}}{\text{W}} \tag{4}$$

Where W is the seasonally applied irrigation depth (m3/ha), and Y is the onion yield (kg/ha).

2.9. Data Analysis

GenStat software was used to do an analysis of variance (ANOVA) on the data. At the 5% level of probability, treatment averages were compared using the least significant difference (LSD).

3. Results and Discussions

3.1. Analysis of Soil Properties of the Experimental Site for CWR Input

The soil physical property used for CropWat input was used for the determination of the crop water requirement of onion.

Table 2. Soil physical properties of experimental site.

D (cm)	Sand	Clay	silt	Textural class	BD (g/cm3)	FC (%)	PWP (%)	TAW (mm/m)
0-15	47	27	26	Sandy clay loam	1.31	30.60	19.20	149.34
15-30	43	30	27	Clay loam	1.20	30.20	18.00	146.40
30-45	43	33	24	Clay loam	1.13	32.40	20.20	137.86
45-60	41	35	24	Clay loam	1.14	35.30	22.80	142.50
Total available water in the effective root zone of mm/m								144.02

The average percentages of clay, silt, and sand were 32, 25, and 43, respectively, according to the results of the soil physical property analysis. Therefore, the particle size distribution of the experimental location indicated that the soil textural class is clay loam based on the USDA soil textural classification. The experimental site's bulk density was determined to be between 1.13 and 1.31 g/cm3. The research area's bulk density was suitable for crop development and the flow of water and air through the soil, according to [15].

3.2. Onion Irrigation Scheduling Was Applied Based on the SMDL Treatment

Based on the treatment, different irrigation schedules at different onion growth stages were obtained, and water consumption was also determined.

Table 3. Onion irrigation scheduling applied based on SMDL treatment.

Treatments	Depletion fraction (P)	Irrigation frequency	Irrigation interval				Water used (m3/ha)
			Initial	Mid	Dev	End	
60% ASMDL	0.21	22	4	5	6	9	5198.3
80% ASMDL	0.28	19	5	6	7	10	4861.6
100% ASMDL*	0.35	15	5	7	8	11	4713.3
120% ASMDL	0.42	13	6	11	12	15	4603.3
140% ASMDL	0.49	9	10	14	15	16	4271.6

Table 3 shows that irrigation water, maximum irrigation frequency, and short irrigation interval were obtained by scheduling irrigation at 60% of ASMDL treatment. This implies that as irrigation intervals are close to each other, more irrigation water is consumed by this treatment. The next maximum irrigation frequency was obtained by scheduling irrigation at 80% of ASMDL treatment. Minimum irrigation frequency and minimum water consumed by scheduling irrigation at 140% ASMDL treatment.

3.3. How Soil Moisture Depletion Affects Onion Production and Yield Components

The treatment significantly affected the yield and yield components of onion when irrigation was scheduled at different soil moisture depletion levels.

Table 4. Effect of Soil moisture depletion level on onion yield and yield components.

Treatments	PH (cm)	Bulb diameter (cm)	Bulb yield (qt ha-1)
60% ASMDL	49.83 a	5.083 a	317.2 a
80% ASMDL	44.83 b	4.350 b	310.0 a
100% ASMDL*	42.50 c	3.500 c	277.8 b
120% ASMDL	36.17 d	3.000 cd	261.7 c
140% ASMDL	31.83 e	2.833 d	208.9 d
CV	3.1	13.7	4.7
LSD	1.52	0.62	15.49

The above ANOVA Table 4 showed that different irrigation schedule treatments had a significant effect on onion yield and yield components. The results show that the maximum onion yield was obtained by scheduling irrigation at 60% of ASMDL treatment, followed by 80% ASMDL treatment. Statistically, there is no significant difference between 60% ASMDL and 80% ASMDL treatments in terms of bulb yield. The result is in line with [14], who report that the highest onion bulb yield (363.9 qt/ha) was obtained from 60% ASMDL. By scheduling irrigation at 140% of ASMDL treatment, the minimum onion production was achieved. This implies that as the onion is more stressed and the irrigation interval increases, onion yield decreases. The result also indicates that both plant height and bulb diameter were decreased as the irrigation interval elongated or became farther apart. The result is in line with the findings of [16], who report that bulb diameter decreased as the crop is more stressed.

3.4. Effect of Soil Moisture Depletion Level on Onion Water Productivity

The water productivity of onion is affected by different irrigation scheduling treatments. There is a significant difference between treatments at different soil moisture depletion treatments.

Table 5. *Effect of Soil moisture depletion level on onion water productivity.*

Treatments	Bulb yield (qt ha-1)	Water productivity (kg/m3)
60% ASMDL	317.2a	10.171ab
80% ASMDL	310.0a	10.627a
100% ASMDL	277.8b	9.812b
120% ASMDL	261.7c	10.064b
140% ASMDL	208.9d	8.150c
CV	4.7	4.5
LSD	15.489	0.523

Maximum water productivity was obtained by scheduling irrigation at 80% ASMDL treatment followed by 60% ASMDL treatment. Statistically, there is no significant difference between 60%, 100%, and 120% ASMDL treatments in terms of onion water productivity. Water productivity was at its lowest when irrigation was scheduled at 140% ASMDL treatment.

3.5. Effect of Irrigation Scheduling on Ky and the Yield Reduction of Onion

From the result, it’s observed that the percent of yield reduction increases when the crop is more stressed, and the irrigation interval is elongated.

Table 6. *The impact of irrigation timing on Ky and the decrease of onion output.*

Treatments	Yield (qt/ha)	Yield reduction (%)	Yield response factor Ky.
60% ASMDL	317.2a	-	-
80% ASMDL	310.0a	-	-
100% ASMDL	277.8b	*	*
120% ASMDL	261.7c	5.79	2.46
140% ASMDL	208.9d	24.80	1.53

The result showed that both the 120% and 140% ASMDL treatments had yield response factors (Ky) greater than one. Onion yield is significantly reduced as a result of treatments when ky is more than one. At those treatments, the yield drop as a percentage was likewise large, suggesting that irrigation scheduling results in a notable yield reduction.

4. Conclusions and Recommendations

The study was carried out at Kombolcha District, in East Hararghe Zone, Oromia Regional State, Ethiopia, during the 2022/23 and 2023/24 irrigation seasons to assess the impact of various irrigation regimes on Onion productivity and water use. Using five irrigation treatments based on allowed soil moisture depletion levels (ASMDL) 60%, 80%, 100%, 120%, and 140%, the experiment was set up in three replications using a Randomized Complete Block Design (RCBD).

The Eastern Hararghe Zone's onion production under furrow irrigation is biologically and economically optimal at 80% ASMDL, according to the study's findings. The 80% ASMDL treatment preserved a steady soil moisture tension that supported continuous physiological development, in contrast to the traditional 100% depletion level.

The result of the effect of different irrigation schedules on onion indicates that maximum water productivity (10.627 kg/ha) and optimum yield (310.0 qt/ha) were obtained by scheduling irrigation at 80% ASMDL treatment over other treatments. Hence, for onions with 5- day, 6-day, 7-day, and 10-day irrigation intervals at the initial, development, mid, and maturity stages of onions, respectively, in the study area and the same agro-ecology, scheduling irrigation at 80% ASMDL (at $p < 0.5$) has been advised.

Abbreviations

ANOVA	Analysis of Variance
ASMDL	Allowed Soil Moisture Depletion Levels
BD	Bulk Density
CWR	Crop Water Requirement
ETo	Reference Evapotranspiration
FC	Field Capacity
KPT	Kombolcha Polytechnique
LSD	Least Significant Difference
PE	Effective Rainfall
PWP	Permanent Welting Point
RCBD	Randomized Complete Block Design
SMDL	Soil Moisture Depletion Levels
TAW	Total Available Water
USDA	United States Department of Agriculture

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Author Contributions

Ayela Tade: Conceptualization, Formal Analysis, Funding acquisition, Software, Writing – original draft, Writing – review & editing

Lalisa Ofga: Data curation, Funding acquisition, Investigation, Methodology, Visualization

Jemal Nur: Conceptualization, Data curation, Investigation, Methodology, Visualization

Conflicts of Interest

The authors declare no conflicts of interest.

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