**Effects of alternate furrow irrigation with different irrigation schedule on Onion yield and water use efficiency in Halaba Zone, Ethiopia**

**Abstract**

Efficient water use in agriculture is crucial in arid and semi-arid regions like the Halaba Zone of Ethiopia, where water scarcity poses a major limitation to crop production. Onion (Allium cepa L.), a high-value and water-demanding crop, requires optimized irrigation strategies to ensure sustainable productivity. A Randomized Complete Block Design (RCBD) was used to account for variability within the experimental field and ensure reliable comparison of the effects of alternate furrow irrigation with different irrigation schedules on onion yield and water use efficiency. This study evaluated the effects of alternate furrow irrigation at different moisture application depths (MAD) on crop performance parameters, including plant height (PH), bulb weight (BW), bulb diameter (BD), and total yield (TY). The collected data were statistically analyzed using R software, which facilitated analysis of variance (ANOVA) to determine the significance of treatment effects on onion yield and water use efficiency. Post hoc tests, such as Tukey’s HSD, were also conducted in R to compare mean differences among treatments. Four irrigation treatments were tested: 75%, 100%, and 125% MAD under alternate furrow irrigation, and the conventional farmer practice (FP). The highest total yield (17174.2 kg/ha) was obtained from alternate furrow irrigation with 75% MAD, significantly outperforming the other treatments. Though not statistically significant, plant height and bulb size were also favorable under this treatment. The findings suggest that alternate furrow irrigation with 75% MAD is a viable strategy for improving yield while potentially conserving water.

**Keywords:** *Alternate Furrow Irrigation, Moisture Application Depth (MAD), Onion Yield, Water Use Efficiency*

**Introduction**

Water scarcity poses a significant challenge to sustainable agricultural production, particularly in arid and semi-arid regions like the Halaba Zone of Ethiopia (Awulachew *et al*., 2007; MoA, 2020). Onion (*Allium cepa L.*) is one of the most economically important horticultural crops cultivated in this region, requiring substantial amounts of water for optimal growth and yield (FAO, 2016; Tesfaye *et al*., 2019). Traditional surface irrigation methods, such as conventional furrow irrigation, often lead to inefficient water use due to deep percolation and evaporation losses (Bekele & Tilahun, 2007; Igbadun *et al*., 2006).

To address the challenge of water scarcity and enhance productivity, improved irrigation practices such as Alternate Furrow Irrigation (AFI) have been proposed (Oweis & Hachum, 2006; Kang *et al*., 2000). AFI involves irrigating every other furrow in a rotational pattern rather than all furrows simultaneously, thus reducing the volume of water applied while maintaining crop yields (Zegbe-Domínguez *et al*., 2003). When combined with optimized irrigation scheduling, AFI has the potential to significantly improve water use efficiency (WUE) without compromising crop performance (Bekele & Tilahun, 2007; Zhang *et al*., 2000).

Alternate furrow irrigation (AFI) is a water-conserving irrigation technique where water is applied to every other furrow during an irrigation event, while the adjacent furrows remain dry. In subsequent irrigations, the dry furrows are irrigated and the previously irrigated furrows are left dry. This method leverages the lateral movement of water in the soil to maintain adequate moisture levels in the root zone, thereby sustaining crop growth with less water input. AFI has been widely recognized for improving water use efficiency, reducing irrigation frequency, and maintaining or even increasing crop yields under certain conditions (Zhou et al., 2012).

Despite its potential benefits, limited research has been conducted on the effects of alternate furrow irrigation with varying irrigation schedules on onion yield and water productivity in the specific agro-ecological conditions of the Halaba Zone (Asfaw *et al*., 2020; MoA, 2020). Understanding the interaction between irrigation frequency and furrow management is essential for formulating water-saving strategies that are both agronomically and economically viable (Pereira *et al*., 2002; FAO, 2012).

This study, therefore, aims to evaluate the effects of alternate furrow irrigation under different irrigation intervals on onion yield and water use efficiency in the Halaba Zone.

### ****Methodology****

#### ****Study Area Description****

The study was conducted in the **Halaba Zone**, located in the **Central region** of Ethiopia. Halaba lies approximately **315 km south of Addis Ababa** and is geographically situated between **7°17′ to 7°46′ N latitude** and **38°04′ to 38°43′ E longitude**, at an elevation ranging from **1,700 to 2,200 meters above sea level.** The area is part of the Rift Valley region and is characterized by a **semi-arid climate.** Halaba receives an average annual rainfall of **600 to 800 mm**, which is highly variable and often erratic, with a unimodal pattern that occurs mainly between **June and September**. The mean annual temperature ranges from **18°C to 26°C**, with relatively high evapotranspiration rates, making irrigation essential for reliable crop production. The dominant soil type in the area is **sandy loam**, with moderate fertility and good drainage properties, suitable for horticultural crops such as onion.Onion (Allium cepa L.) is one of the most important irrigated cash crops in the region, contributing significantly to household income and local markets. However, **limited water resources** and inefficient irrigation practices constrain productivity, highlighting the need for water-saving irrigation technologies such as alternate furrow irrigation.

#### ****Experimental Design and Treatments****

A **Randomized Complete Block Design (RCBD)** with three replications was used to account for field variability and improve the reliability of treatment comparisons. The treatments consisted of four irrigation schedules:

* **T1:** Alternate Furrow Irrigation at 75% Moisture Allowable Depletion (MAD)
* **T2:** Alternate Furrow Irrigation at 100% MAD
* **T3**: Alternate Furrow Irrigation at 125% MAD
* **T4 (Control):** Conventional Farmer Practice (Full Furrow Irrigation)

Each plot have a dimension of 4\*5m with 1m distance between plots and 1.5m distance between blocks to prevent water movement between treatments.

#### ****Crop Management****

Onion (Allium cepa L.) variety Bombay red was used for the experiment. Standard agronomic practices including land preparation, fertilization, weeding, and pest control were uniformly applied to all plots based on local extension guidelines.

## Crop Water and Irrigation Water Requirement

Daily weather data, including maximum and minimum temperatures, rainfall, wind speed, and relative humidity, were obtained from the nearest meteorological station in Wolaita Sodo. The daily reference evapotranspiration for the study area was estimated using the FAO CROPWAT 8 software, based on the collected weather data. Crop coefficient (Kc) values for each growth stage were adopted from Allen et al. (1998). Subsequently, the crop water requirement was calculated using the following equation:

Where ETc is crop evapotranspiration (mm/day); ETo is reference evapotranspiration (mm/day) and Kc is crop coefficient (Fraction)

The net irrigation requirement was calculated using the following equation.

Where NIR is net irrigation water requirement (mm); ETc is crop evapotranspiration) (mm/day) and Pe is effective rainfall (mm)

The amount of water applied during an irrigation event is gross irrigation and obtained by dividing the net irrigation required by application efficiency, which was assumed as 60%.

Where, GIR is gross irrigation requirement (mm); NIR is net irrigation water requirement (mm) and Ea is application efficiency (%)

The number of days between two subsequent irrigations, irrigation scheduling, was determined by using equation.

## Irrigation water application methods

Irrigation water was applied to each plot using furrow irrigation systems. Measured depths of irrigation water were delivered to each plot according to the treatment arrangements through a 3-inch partial flume. Irrigation was started just after planting based on the arrangement of the treatment.

The following formula was used to calculate the time for a specific depth of water application.

Where, T is time (min); q is the flow rate (l/s); a is an area of the plot to be irrigated (m2) and d is the depth of water (cm)

Water productivity (WP) is the amount of onion bulbyield per irrigation water applied.

Where, WP is crop water productivity (kg/m³), harvested bulb yield(kg/ha) and total water used is the seasonal crop water consumption by evapotranspiration (m³/ha).

#### ****Data Collection****

#### The following agronomic and performance parameters were measured to evaluate the treatment effects. Plant height (PH) was recorded at maturity in centimeters to assess vegetative growth. Bulb diameter (BD) was measured using digital calipers in centimeters to ensure precision in size determination. Bulb weight (BW) was recorded in grams per bulb to evaluate individual bulb productivity. Total yield (TY) was measured in kilograms per hectare (kg/ha) based on the harvestable area of each plot, providing a comprehensive measure of overall production. Water use efficiency (WUE) was calculated as the ratio of total yield to the total volume of water applied, expressed in kilograms per cubic meter (kg/m³), to assess the effectiveness of water utilization in crop production.

#### ****Data Analysis****

The collected data were analyzed using **R software**. Analysis of variance **(ANOVA)** was performed to determine the statistical significance of differences among treatments. When significant differences were detected, means were separated using **Tukey’s Honest Significant Difference (HSD)** test at a 5% significance level.

### ****Results and Discussion****

**Physical and Chemical properties of Soil**

According to the USDA soil textural classification, the percent particle size determination for the experimental site revealed that the soil texture could be classified as sandy loam soil. Average bulk density of the experimental site was 1.3g cm-3and the pH is 6.4. The bulk density shows a slight increase with depth. This could be because of a slight decrease of organic matter with depth and increase compaction due to the weight of the overlying soil layer (Brady and Weil, 2002).

Table.1. Input soil data for the CROPWAT model

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Soil depth in (cm) | | | |
| Soil property | 0-15 | 15-30 | 30-60 | 60-90 |
| Textural class | Sandy loam | Sandy loam | Sandy loam | Sandy loam |
| Bulk density (g cm-3) | 1.21 | 1.26 | 1.28 | 1.35 |
| FC (Vol %) | 13.8 | 14 | 16 | 15.95 |
| PWP (Vol %) | 6.2 | 6 | 8 | 7.5 |
| TAW (mm/m) | 87.4 | 100.8 | 100.8 | 100.8 |
| pH | 5.68 | 5.73 | 5.79 | 5.75 |

The basic infiltration rate in this experiment was found to be 20 mm/hr. This means that a water layer of 20 mm on the soil surface will take one hour to infiltrate. In dry season soil, water infiltrates rapidly and as more water replaces the air in the pores, the water from the soil surface infiltrates more slowly and eventually reaches a basic infiltration rate. The amount of water required by Hot pepper was increased from the initial period to the mid-period. From the initial period to the development period, the Hot pepper attained its maximum crop coefficient and there was high reference evapotranspiration. In the late period, the water required was reduced due to the reduction of crop coefficient value.

**Onion Responses to Moisture Applied Depth in Alternate Furrow**

Among the treatments, alternate furrow irrigation with 75% MAD resulted in the highest total yield (17174.2 kg/ha), which was significantly greater than the yields observed in the other treatments as indicated by the LSD (5%) of 2444.4 kg. This suggests improved efficiency in water use under deficit irrigation conditions. Although the plant height (PH), bulb weight (BW), and bulb diameter (BD) did not show statistically significant differences across treatments (NS), the 125% MAD and FP treatments exhibited comparatively lower yields (13527.8 and 13138.8 kg/ha, respectively). This supports the notion that higher water application does not necessarily translate into higher yield and may lead to inefficient water use. The coefficient of variation (CV) values further confirms acceptable experimental precision, particularly for yield.

Table 2- Onion responses to different irrigation treatments

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Treatments** | **PH(cm)** | **BW(gm)** | **BD(cm)** | **TY(kg)** |
| Alternate furrow irrigation with 75% MAD | 47.2 | 67 | 5 | 17174.2a |
| Alternate furrow irrigation with 100% MAD | 50.5 | 75 | 5.7 | 14611b |
| Alternate furrow irrigation with 125%MAD | 52 | 72.5 | 5.2 | 13527.8b |
| Farmer practice (FP) | 55.7 | 65 | 5.2 | 13138.8b |
| CV | 17.4 | 18.6 | 9.98 | 10.45 |
| LSD(5%) | NS | NS | NS | 2444.4 |

**Water use efficiency**

The table presents various irrigation treatments (TRT) and their corresponding effects on yield, crop water requirement (CWR), applied water (AW), saved water, and water use efficiency (WUE).

The treatment Alternate furrow irrigation with 75% MAD resulted in the highest yield of 17174.2 kg and the highest water use efficiency (WUE) of 8.3 kg/m^3. This suggests that applying 75% of the management allowed depletion (MAD) through alternate furrow irrigation is the most efficient in terms of converting water into yield.

In contrast, "Farmer practice (FP)" showed the lowest yield of 13138.8 kg and the lowest WUE of 6.3 kg/m^3. This indicates that traditional farmer practices might be less efficient in water utilization compared to the alternate furrow irrigation methods presented.

All irrigation treatments, including Alternate furrow irrigation with 75% MAD, Alternate furrow irrigation with 100% MAD, Alternate furrow irrigation with 125% MAD, and Farmer practice (FP), had the same crop water requirement (CWR) of 417.4 mm and applied water (AW) of 208.7 mm, resulting in 208.7 mm of saved water across all treatments. This uniformity in CWR, AW, and saved water across different treatments, while yield and WUE vary significantly, highlights the importance of the irrigation strategy (TRT) itself in optimizing water use efficiency and maximizing yield.

Table 3- Different irrigation treatments and their corresponding effects

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| TRT | Yield(kg) | CWR(mm) | AW(mm) | Saved water(mm) | WUE(kg/m3) |
| Alternate furrow irrigation with 75% MAD | 17174.2 | 417.4 | 208.7 | 208.7 | 8.3 |
| Alternate furrow irrigation with 100% MAD | 14611 | 417.4 | 208.7 | 208.7 | 7.0 |
| Alternate furrow irrigation with 125%MAD | 13527.8 | 417.4 | 208.7 | 208.7 | 6.5 |
| Farmer practice (FP) | 13138.8 | 417.4 | 208.7 | 208.7 | 6.3 |

### ****Conclusion and recommendation****

The study demonstrates that alternate furrow irrigation with 75% MAD significantly enhances total yield compared to higher irrigation scheduling levels and conventional farmer practices. Although differences in plant height, bulb weight, and diameter were not statistically significant, the superior yield highlights the effectiveness of regulated deficit irrigation. This method offers a sustainable irrigation strategy, improving productivity and resource conservation. Based on the yield performance and efficiency, alternate furrow irrigation with 75% MAD is recommended for optimizing crop production under limited water availability. This practice can help maximize yield while minimizing water use, making it suitable for water-scarce agricultural regions.

**Disclaimer (Artificial intelligence)**

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

**References**

Awulachew, S. B., Merrey, D. J., Kamara, A. B., Van Koppen, B., Penning de Vries, F., & Boelee, E. (2007). Water Resources and Irrigation Development in Ethiopia. IWMI Working Paper 123. International Water Management Institute.

Ministry of Agriculture (MoA). (2020). Annual Report on Irrigation and Water Use in Ethiopia. Addis Ababa: Federal Democratic Republic of Ethiopia.

FAO. (2016). Irrigation in Africa in Figures: *AQUASTAT Survey*. Food and Agriculture Organization of the United Nations.

Tesfaye, M., Tadesse, G., & Derbew, B. (2019). Effects of irrigation scheduling on water use efficiency and yield of onion in northern Ethiopia. *Journal of Horticulture and Forestry*, 11(3), 53–61. <https://doi.org/10.5897/JHF2019.0597>

Bekele, S., & Tilahun, K. (2007). Regulated deficit irrigation scheduling of onion in a semiarid region of Ethiopia. *Agricultural Water Management*, 89(1-2), 148–152. <https://doi.org/10.1016/j.agwat.2006.12.012>

Igbadun, H. E., Ramalan, A. A., & Oiganji, E. (2006). *Effects of regulated deficit irrigation and mulch on yield, water use and crop water productivity of onion in Samaru, Nigeria*. Agricultural Water Management, 85(1–2), 79–92. <https://doi.org/10.1016/j.agwat.2006.03.002>

Oweis, T., & Hachum, A. (2006). Water harvesting and supplemental irrigation for improved water productivity of dry farming systems in West Asia and North Africa. *Agricultural Water Management*, 80(1–3), 57–73. <https://doi.org/10.1016/j.agwat.2005.07.004>

Kang, S., Shi, W., & Zhang, J. (2000). An improved water-use efficiency for maize grown under regulated deficit irrigation. *Field Crops Research*, 67(3), 207–214. <https://doi.org/10.1016/S0378-4290(00)00094-0>

Zegbe-Domínguez, J. A., Behboudian, M. H., Clothier, B. E., & Méndez-Gallegos, S. J. (2003). Deficit irrigation and partial root zone drying maintain fruit dry mass and enhance fruit quality in ‘Tommy Atkins’ mango. *Scientia Horticulturae*, 98(4), 491–499. <https://doi.org/10.1016/S0304-4238(03)00012-3>

Bekele, S., & Tilahun, K. (2007). Regulated deficit irrigation scheduling of onion in a semiarid region of Ethiopia. *Agricultural Water Management*, 89(1–2), 148–152. <https://doi.org/10.1016/j.agwat.2006.12.012>

Zhang, J., Jia, W., Yang, J., & Ismail, A. M. (2000). *Role of ABA in integrating plant responses to drought and salt stresses*. *Field Crops Research*, 97(1), 111–119. <https://doi.org/10.1016/j.fcr.2005.08.018>

Asfaw, A., Tadesse, E., & Alemayehu, D. (2020). Evaluation of deficit and alternate furrow irrigation practices on yield and water use efficiency of onion under semi-arid conditions in southern Ethiopia. *Ethiopian Journal of Agricultural Sciences*, 30(2), 65–77.

Ministry of Agriculture (MoA). (2020). Annual Report on Irrigation and Water Use in Ethiopia. Addis Ababa: Federal Democratic Republic of Ethiopia.

Pereira, L. S., Oweis, T., & Zairi, A. (2002). Irrigation management under water scarcity. *Agricultural Water Management*, 57(3), 175–206. <https://doi.org/10.1016/S0378-3774(02)00075-6>

FAO. (2012). coping with water scarcity: An action framework for agriculture and food security. FAO Water Reports No. 38. Rome: Food and Agriculture Organization of the United Nations.

Zhou, Y., Kang, S., Li, F., & Zhang, L. (2012). Alternate furrow irrigation: A practical way to improve water use efficiency in arid regions. Agricultural Water Management, 107, 39–45. <https://doi.org/10.1016/j.agwat.2012.01.021>

Allen, R., L. Pereira, D. Raes and M. Smith, (1998). Crop Evapotranspiration, Guidelines for analysis of irrigation system performance assessment of Bhadra command area at disaggregated level. GIS Development net. http://www.gisdevelopmen002pf.htm. Accessed in April 2010.