Evaluating the impact of different furrow irrigation methods on onion bulb yield and water productivity: The case of Hadero Tunto district, Southern Ethiopia

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ABSTRACT

The aim of this study was to evaluate the effectiveness of different furrow irrigation methods on bulb yield and water productivity. The experiment was conducted in farmers' fields using a Randomized Complete Block Design, with three treatment levels and five replications. The irrigation methods tested included Alternate Furrow Irrigation (AFI), Fixed Furrow Irrigation (FFI), and Conventional Furrow Irrigation (CFI). The results indicate that furrow irrigation methods significantly influence bulb diameter, yield, and water productivity. The harvested bulb yields were 10.26 t/ha for AFI, 10.32 t/ha for CFI, and 9.36 t/ha for FFI. The maximum water productivity values were 4.8 kg/m³ for AFI and 4.1 kg/m³ for FFI, both achieved with a consistent seasonal crop water requirement of 228.3 mm. In contrast, the CFI method yielded a minimum water productivity of 2.26 kg/m³, with a total applied water depth of 456.6 mm. A partial budget analysis revealed the following net returns: 682,020 ETB/ha for AFI, 560,500 ETB/ha for FFI, and 678,540 ETB/ha for CFI. The benefit-cost ratios were highest for AFI at 12.03, followed by CFI at 10.52, and FFI at 9.89. Based on these findings, we recommend the Alternate Furrow Irrigation method for enhancing onion bulb yield and water productivity, particularly in water-scarce regions with similar agroecological conditions.

Keywords: Onion bulb yield; Furrow irrigation methods; Water productivity; Economic income
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INTRODUCTION

Irrigated agriculture plays a significant role in the field of agriculture, growing crops, maintaining the landscape, and re-vegetating disturbed soils in dry areas during periods of low rainfall (Tigabie *et al.*, 2023). The furrow irrigation method is the most popular and widely used surface irrigation technique for producing vegetables, including onions, across nearly all regions of Ethiopia (Ligalem *et al.*, 2022). Conventional furrow irrigation (CFI) involves the application of irrigation water to every furrow throughout the irrigation period. This method has led to increased decomposition rates and the loss of organic matter and mobile nutrient forms in the root zone, ultimately resulting in soil fertility loss (Karajeh *et*

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al., 2000). CFI is known to be less efficient, particularly in times of water scarcity (Tilaye *et al*., 2021). Proper furrow irrigation practices can minimize water application and irrigation costs, save water, control soil salinity buildup, and result in higher crop yields (Hodges *et al*., 1989). Efficient dosing of irrigation water enhances crop production and boosts water productivity for future needs (Taddesse and Peden, 2001). Irrigation water management ensures that the water level in the crop root zone remains within a range that does not harm crop yield and quality due to inefficiency or overwatering (Geremew *et al*., 2008). Alternate furrow irrigation (AFI) is considered one of the most effective methods for minimizing water use and irrigation costs while producing higher crop yields (El-Halim, 2013). This approach allows for reduced irrigation volumes and enables quicker irrigation of fields with a given water supply (Tilaye *et al*., 2022). When water supply is limited, irrigation water is applied through alternate furrows, saving significant amounts of water in areas with scarce resources (Majumdar, 2002). The fixed furrow irrigation (FFI) system supplies water to one side of each furrow ridge throughout the irrigation period, resulting in a trade-off between lower yields and higher water use efficiency (Kang *et al*., 2000). Proper allocation and management of irrigation water are essential technologies for sustainable cultivation in areas facing water scarcity (Ashraf *et al*., 2007; Azizi and Zamani, 2009). Therefore, this study was conducted to evaluate and demonstrate the effect of furrow irrigation methods on onion bulb yield, water productivity, farm gate income generation, and farmers' perception of technology adoption.

MATERIALS AND METHODS

Description of the study area

The experiment was conducted on the midland agroecology of the Gombolozo irrigation scheme, which covers a total command area of 65.124 ha from the first Tunto and Gelibe Kebeles, Hadero Tunto district, Kambata Zone, and Central Ethiopia Region. The study area is geographically located at latitude of 7°14'43", a longitude of 37°38'20", and an altitude of 1750m under midland agroecology. The mean maximum and minimum temperatures were 25.6 °C and 14.48 °C, respectively. The district has two major agroecological zones, Dega and Weyne Dega, covering 38.46% and 61.54%, respectively. The mean annual rainfall of the district ranges from 1200–1500 mm (Hadaro *et al*., 2021). The potential irrigable crops grown in the area include onion, tomato, head cabbage, hot pepper, wheat, banana, and mangoes. Onions were selected for the study based on farmers' preferences, considering disease resistance, yield potential, seasonal local market linkage, and daily home edible food availability compared with other vegetable crops. Figure 1 shows the map of the study area.

Crop water requirements and irrigation water management

The total water requirement after transplanting onion crops grown in the field ranges from 100 to 140 days and requires 350 to 550 mm of irrigation water depending on the climate of the environment, whereas crop evapotranspiration refers to the amount of water that is lost through evapotranspiration (Allen *et al*., 1998).

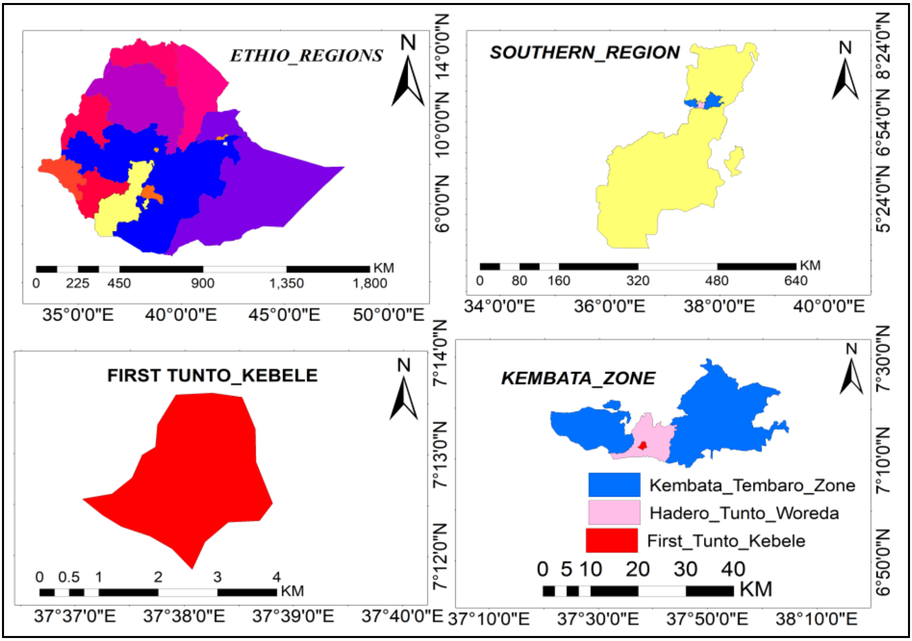

Figure 1. Map of study area

Experimental design and treatment

The experiment was laid out in a Randomized Complete Block Design (RCBD) with three treatments and five replicates (farmers were used for replication). The treatments were Alternating Furrow Irrigation (AFI), Fixed Furrow Irrigation (FFI) and Conventional Furrow Irrigation (CFI). The size of each plot was 10 m by 10 m. The space between the plots was 1m, space between plants to plant, ridge to ridge and furrow to furrow was 10cm, 20cm and, 40cm respectively. NPS (200 kg/ha) and Urea (100 kg/ha) were used as fertilizer and urea was applied 30- 45 days after transplanting especially during the first weeding.

The effective root zone depth (R_Z) of onion ranges on average up to 0.6 m and has a maximum allowable depletion (MAD) of 25% (Andreas *et al*, 2002). Onion average values of crop coefficient (Kc) were taken after adjustments were made for initial 0.5, development 0.78, mid 1.03, and late season stage 0.88 (Doorenbos and Kassam, 1979). The irrigation water requirement was calculated by using the formulae:

$$ETc = ETo \times Kc$$

ETc-Crop Evapotranspiration, Kc-Crop Coefficient, ETO-Reference Evapotranspiration.

$$Bd = \left(\frac{Md}{V_c}\right)$$

Bd-bulk density, Md- dry mass of the soil and VC-Volume of core sampler.

$$TA = \frac{(FC - PWP) * Bd * Rd}{100}$$

TAW-(available water), FC-(field capacity), PWP-(permanent wilting point), Bd-bulk density and Rd-root depth.

$$RAW = (TAW * p)$$

RAW-readily available water in mm, P (40%)-Allowable/permissible soil moisture depletion for no stress.

$$NI = (ETc_{mm} - Peff_{mm})$$

NI-Net irrigation, ETc-Seasonal Crop Water Requirement, Peff-Effective rain fall.

$$GI = \frac{NI}{Ea}$$

GI-Gross Irrigation, NI-Net Irrigation, and Ea- application efficiency, but Ea=Application Efficiency for surface irrigation (60%).

$$T = \frac{L * W * Dg}{6Q}$$

T-application time (min), Dg- gross depth of water applied (cm), and L- furrow length in (m), W- furrow width (m), and Q-flow discharge (l/s).

Water productivity

Water productivity plays a crucial role in modern agriculture which aims to increase yield production per unit of water used, both under rain fed and irrigated conditions. Water productivity with dimensions of kg/m3 is defined as the ratio of the mass of marketable yield (Y) to the volume of water consumed by the crop (Wa). Mathematically, water productivity can be represented as follows in the equation (Ali and Talukder, 2008).

$$WP = \frac{Y}{Wa}$$

WP-Water Productivity (kg/m3), Y-Economic Yield (kg), and Wa- Total Water applied (m3).

Economic analysis

The focus of this study was solely on the changes in income and expenses resulting from the implementation of a specific alternative. It aim was to compare the effects of alternate furrow water application along with other input costs, starting from land preparation to marketing and returns for producers across different treatments. Economic analysis, as suggested by CIMMYT (1988), was employed to evaluate water application levels based on cost and benefits.

Data collection and analysis

Data like soil, climate, agronomic and water data were collected according to its procedure and standards. The collection process was done through gathering, measuring, and analyzing for the interpretation of the results.

Soil data

The soil sample was collected from different depths 0-20 cm, 20-40 cm, and 40-60 cm up to the root depth of the onion for analysis of same selected physical and chemical properties by using a sampling auger. The parameters analyzed were soil texture, field capacity, permanent wilting point, pH, electrical conductivity of the soil (ECe), bulk density (Bd), organic matter (OM %), organic carbon (OC %), total nitrogen (TN %) and available phosphorus (pmm).

Climate data

Some of the climatic data collected were maximum and minimum temperature, precipitation, sunshine, relative humidity, wind speed, wind direction, and solar radiation from the nearby meteorology station. The data collected were used for the calculation of reference evapotranspiration (ETo).

Agronomic data

Some of field agronomic data like plant height, bulb diameter, bulb weight, total marketable yield, and amount of irrigation water applied were measured in the field. Plant height and bulb diameter were measured with a tape meter, and both bulb weight and total yield were measured with a weighing beam balance. Irrigation water applied to the field was measured with calibrated three inch Parshall flume within three days interval for initial stage and five days interval for rest growing seasons. All appropriate data collected was subjected to Statistix 10.0 software for analysis. The factor of the experiment was considered as single factorial Randomized Complete Block Design (RCBD) for analysis. The data collected for all relevant variables were subject to analysis of variance (ANOVA) which is appropriate for Randomized Complete Block Design (RCBD) (Gomez and Gomez, 1984).

RESULTS AND DISCUSSION

Physical properties of the soil

The laboratory results for the average physical and chemical properties of the soil at the experimental site are presented below. The soil is classified as clay, which constitutes the majority of the particle distribution. This texture is well-suited for both alternate and fixed furrow irrigation systems, as it facilitates lateral water flow towards the opposite sides of the furrows.

The average bulk density of the experimental site was measured at 1.27 g/cm^3, as shown in Table 1. The critical bulk density value that restricts root growth varies depending on soil type (Hunt and Gilkes, 1992). Generally, a bulk density exceeding 1.6 g/cm^3 can impede root development (McKenzie *et al.*, 2002). Sandy soils typically exhibit higher bulk densities, ranging from 1.3 to 1.7 g/cm^3, compared to fine silts and clays, which range from 1.1 to 1.6 g/cm^3. This difference is due to sandy soils having larger, yet fewer, pore spaces. Furthermore, bulk density tends to increase with compaction at greater depths, and very compacted subsoils or strongly indurated horizons may exceed 2.0 g/cm^3 (Turner, 2001; Cresswell and Hamilton, 2002).

Table 1. Physical and chemical properties of the soil

Soil	Clay (%)	Sand (%)	Silt (%)	Textural Class	FC (%)	PWP (%)	Bd(g/cm3)
Value	50	29	21	Clay	42.2	29.5	1.27

Chemical properties of the soil

The pH value of the soil was 5.91 as shown in Table 2; in which crops can be grown on a wide range of soil but a well-drained, with range of 5 to 7 is preferred (Doorenbos *et al.*, 1979). The moisture content of the soil is 23.1% per meter depth Soil. The value of ECe 0.65 ds/m is low considering the standard rates in literature (Landon., 1991). Generally, according to USDA soil classification, a soil with electrical conductivity of less than 2.0 dS/m at 25 °C is classified as normal soil for crop production.

Table 2. Chemical properties of the soil

Parameter	pH	ECe (dS/m)	OC (%)	OM (%)	TN (%)	AvP(ppm)
Values	5.91	0.65	1.65	2.85	0.14	16.66

Climatic data of the study area

The average climatic data (maximum and minimum temperature, relative humidity, wind speed, sun shine hours, and solar radiation) on the monthly basis to obtain reference evapotranspiration of the study area were obtained from the New-LocClim 1.10 software through coordinate points of study site (Table 3).

Table 3. Climatic data of study area

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Av
ETo mm/day	3.6	3.9	4.1	3.6	3.6	2.9	2.5	2.7	2.9	3.4	3.6	3.7	3.4

Crop coefficient and growing periods of onion

Crop coefficient and growing period are directly related parameters that affect seasonal irrigation water requirement (Table 4). The crop onion totally took 126 days from transplanting up harvesting with seasonal amount of irrigation water 456.6mm as shown in Table 5.

Table 4. Growing stages and crop coefficient values of onion

Growing period and Kc-Values	Initial	Development	Mid stage	Late stage
Growing Period	19	32	35	40
Kc-Values	0.5	0.78	1.03	0.88

Table 5. The depth of water applied for onion during the growth period

Growth stages of onion crop	Depth of water applied (mm) in each treatments		
	(AFI)	(FFI)	(CFI)
Initial	20.4	20.4	40.8
Development	56.75	56.75	113.5
Mid	71.85	71.85	143.7
Late	79.3	79.3	158.6
Total Seasonal Amount of Water	228.3	228.3	456.6

AFI-Alternate Furrow Irrigation, FFI-Fixed Furrow Irrigation, CFI-Conventional Furrow Irrigation Systems

Seed bed preparation and seedling sowing

Figure 2 indicates that 4 kg/ha base seed was sown on nursery site bed with 1 m×10 m. Cover the bed with mulch grass after sowing the seed and irrigate water with water can. The bed is covered with grass mulch and mulch was removed after seed germination. After thirty five days the seedling was transplanted in to the field when the height reaches 12 cm-15 cm.

Figure 2. Field performance of onion on the seed bed

Onion bulb yield response for different furrow irrigation methods

As shown in Table 6, there were no statistically significant differences in plant height and bulb weight among the treatments. However, bulb diameter and total bulb yield exhibited significant differences between the treatments. The highest bulb yield was achieved using the conventional furrow method, yielding 10.32 t/ha, followed closely by the alternate furrow method at 10.26 t/ha. In contrast, the fixed furrow method, which involves applying irrigation water to only one side of the furrow throughout the growing period, resulted in the lowest bulb yield of 9.36 t/ha. The leeward side of the furrow remained non-irrigated during the entire growing season, contributing to a decrease in total onion bulb yield, as indicated in Figure 3. The advantages of clay soil facilitate lateral movement of irrigation water rather than downward percolation, which enhances water distribution to the plants.

Table 6. Analysis result of onion bulb yield for furrow irrigation methods

Treatments	**PH (cm)**	**BW (gm)**	**BD (cm)**	**TY (t/ha)**
Alternate furrow irrigation	49.6	30.4	48.0a	10.26a
Fixed furrow irrigation	50.2	30.8	45.6b	9.36b
Conventional furrow irrigation	52.6	29.6	48.6a	10.32a
CV	5.34	6.36	2.74	2.65
LSD	Ns	Ns	0.1.9	0.39

PH-Plant Height, BW-Bulb Weight, BD- Bulb Diameter, TY-Total Yield; means followed by the same superscript letter(s) are not significantly different from each other.


Figure 3. Bulb yield data measuring photo

The highest water productivity (4.8 kg/m3) was obtaine on treatment of alternate furrow method and significantly affected in comparison with conventional furrow method (Table 7). The minimum water productivity (2.26 kg/m3) was obtained from treatments of conventional furrow system as shown in Table 7. Conventional furrow method extravagate irrigation water when compared with alternate furrow method. Both the first (4.8 kg/m3) and second (4.1 kg/m3) higher water productivity values were greater than other previous studies of (3.10 kg/m3) in fixed furrow irrigation method (Bekele and Abebo, 2019). But lower bulb yield was observed in fixed furrow method to recommend its water productivity.

Table 7. Analysis result of water productivity

Treatments	Water Productivity (kg/m3)
Alternate furrow irrigation	4.8a
Fixed furrow irrigation	4.1b
Conventional furrow irrigation	2.26c
CV	4.18
LSD	0.22

Economically, farmers benefited significantly, selling their produce at a minimum price of 60 ETB/kg in the seasonal market. The partial budget analysis of the study indicates that the net returns were 682,020 ETB/ha for alternate furrow irrigation, 560,500 ETB/ha for fixed furrow irrigation, and 678,540 ETB/ha for conventional furrow irrigation. The maximum benefit-cost ratio of 12.03 was achieved with the alternate furrow method, followed by 10.52 for conventional furrow and 9.89 for fixed furrow methods, as shown in Table 8. Farmers were purposefully selected for the questionnaire from established research-extension groups within the irrigation scheme. Neighboring farmers preferred the alternate furrow technology based on several criteria. The criteria considered in the study included labor savings, water savings, yield increases, and ease of handling, with labor savings ranked highest, as shown in Table 9. This technology is particularly recommended for water-scarce conditions and clay soils, which promote lateral movement of water rather than downward percolation.

Table 8. Benefit cost ratio analysis

Variable	Cost (ETB/ha)	AFI	FFI	CFI
	Seed	25,600	25,600	25,600
	Land preparation	4800	4800	4800
	Fertilizer	9900	9900	9900
	Pesticide chemicals	5000	5000	2000
	Watering	7800	7800	15600
	Harvesting	3600	3600	3600
Total cost (ETB)		56700	56700	64500
Yield (kg/ha)		10260	9360	10320
10% adjusted yield (kg/ha)		9234	8424	9288
Gross revenue (ETB/ha)		738,720	617,200	74304
Net benefit (ETB/ha)		682,020	560,500	678,540
Benefit cost Ratio		12.03	9.89	10.52

Table 9. Farmers' perception on irrigation scheduling

Sample of participants (N=37) and their feedback						
Criteria	**Labor saving**	**Water saving**	**Yield increment**	**Technology easiness**	**Grand Total**	**Rank**
AFI	18	18	15	15	66	1
FFI	18	19	10	16	63	2
CFI	1	0	12	6	18	3

CONCLUSION AND RECOMMENDATION

Furrow irrigation methods significantly affect bulb diameter, total bulb yield, and water productivity, while having less impact on plant height and bulb weight. The alternate furrow irrigation technology effectively addresses water competition issues and sustainably conserves scarce water resources. Maximum water productivity is achieved with the alternate furrow method. In conclusion, the alternate furrow method not only enhances bulb yield and water productivity but also improves economic income generation and the livelihoods of farmers. Therefore, this irrigation technology should be widely disseminated and scaled up in other irrigation schemes with similar agro-ecological conditions and water potential patterns.

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