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Improving Agricultural Water Productivity with Alternate Furrow Irrigation in Semi-Arid Conditions of Northern Ethiopia

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Author's contribution

The sole author designed, analyzed and interpreted and prepared the manuscript.

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ABSTRACT

The major production constraint in arid and semi-arid areas is scarcity of irrigation water. Thus, improving the management of irrigation water is very crucial to reduce water losses and thereby enhance water use efficiency. Hence, this research was conducted to evaluate the effect of Alternate Furrow Irrigation (AFI) on yield, water use efficiency and economic return of Onion at Hamedo irrigation scheme as compared to Conventional Furrow Irrigation (CFI), at different levels of water application (100, 80 and 60% of crop evapotranspiration (ETc)). Results indicated that AFI maintained almost similar bulb yield but with up to 50% reduction in irrigation amount when compared to CFI. The maximum marketable bulb yield obtained at 100% ETc with CFI was 22.9 ton/ha which is not statistically significant with that of obtained under AFI (20.8 ton/ha). However, the WUE of onion under AFI at 100% ETc was higher (7.12 kg/m^3) than that of CFI at 100% ETc (3.9 kg/m^3). Moreover, the amount of water saved by AFI, at both levels of water (80 and 60% ETc), was also much higher (293.8 - 413.1mm) than even that of 60% ETc under CFI (238.4mm). Overall, under limited water resources, AFI can reduce the costs associated with labor and pumping to the field. Therefore, it can be recommended that AFI is a practical technique to improve agricultural water productivity for irrigated crops in the study area and other similar agro ecologies.

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1. INTRODUCTION

The central zone of Tigray region, Northern Ethiopia, is one of the potential areas for vegetable production in Ethiopia [1,2]. However, shortage of irrigation water in the region in general and in the zone in particular, is the major limiting factor for crop production. The region is characterized as a semi-arid climatic condition which experiences erratic and inadequate rain fall with high temporal and spatial variability that remains insufficient for crop production [3,4]. Accordingly, the erratic and inadequate rainfall on one hand, and the increasing population on the other hand, develop a great interest of increasing irrigated agriculture in the region. Consequently, the regional government together with Non-governmental organization and farmers are engaged in huge development ground water sources like deep and shallow wells [5]. However, the attention given to agricultural water management by the government and farmers is very low. Farmers often irrigate their plot using traditional surface irrigation methods in which there is substantial water losses by runoff and deep percolation [6,7]. As a result, the irrigated area by a farmer having a shallow well is not more than half a ''tsmad'' (1250m^2) while there is more than half a hectare of potential irrigable land and the cost of delivering the water to the field (pumping cost) is very high. Therefore, surface irrigation methods require major changes in water management in order to use the limited water resources efficiently.

Recently elsewhere in the world, there is a growing interest in AFI, an irrigation practice whereby water is applied to alternate furrows instead of every furrow, while the in-between furrows remain dry and yield stress is allowed with minimal effects on yield [8,9,10,11]. Alternate furrow irrigation system may supply water in a manner that greatly reduces the amount of surface wetted leading to less evapotranspiration and less deep percolation. Comparing to CFI, the reduced evapotranspiration is due to a reduction in wet soil surface and the reduced deep percolation is due to the lower wetted surface which result in lower infiltration. Generally, the efficiency of conventional furrow irrigation can be improved by converting it to alternate furrow irrigation [6,12,13].

The conventional furrow irrigation practiced by farmers in the region, where every furrow is irrigated during consecutive watering, is known to be less efficient particularly where there is shortage of irrigation water. Subsequently, this traditional irrigation practices in the region may lead to non-productive water loss, poor moisture distribution uniformity [6,4,7]. Farmers in developing countries like Ethiopia, especially Tigray region, have no chance to adopt pressurized irrigation technologies due to their high initial cost and technical difficulties such as installation, operation and maintenance [14,15]. Accordingly, farmers want to stay with the traditional surface irrigation methods mainly furrow and basin as these methods are simple to operate and maintain based on farmer's knowledge and skill. So, it is fortunate to improve the CFI to AFI that could be easily accepted by farmers. However, before introducing and promoting AFI for adoption, it is important to evaluate it under the soil and climatic conditions of the targeted districts.

The objective of this study is to evaluate the improvements in water productivity, water savings and economic returns that could be achieved with AFI as compared to CFI at different levels of water application with no or insignificant reduction of onion bulb yield. This paper also provides lessons for farmers, extension workers, water managers and decision makers how to use the limited available water more efficiently with AFI and increase their agricultural production by expanding their irrigable land using the saved water.

2. MATERIALS AND METHODS

2.1 Description of the Study Area

The experiment was conducted in Hamedo irrigation scheme, Tigray region, northern Ethiopia for two consecutive years at the Research Station of Axum Agricultural Research Center (Fig. 1). It is located at 14° 41'N and 14° 43'N latitudes and 38° 73'E and 38°75'E longitudes with an altitude of 1390 m a.s.l. According to [16], the soil type of the experimental site was loam to clay loam as a result the field capacity (FC) and permanent wilting point (PWP) of the soil was 26.3% and 10.8% respectively, as indicated in Table 1. The study area is characterized by semi-arid climate where more than 80% of the rainfall occurs during the rainy season from June to September. The average annual rainfall of the area was

650 mm. The mean annual temperature ranges from 12.2℃ to 27.9℃.

2.2 Experimental Design and Treatments

The experiment was laid out in a factorial randomized complete block design (RCBD) with three replications. The experiment consisted of two factors, irrigation method with two application system (conventional and alternate furrow) and irrigation amount with three levels (100, 80 and 60% ETc). The experiment has a total of 2*3 = 6 treatment combinations. The details of the experimental treatments setting and treatment combinations are presented in Table 1. The spacing between plants and rows was 10 cm and 60 cm respectively, based on the practices' of farmer in the study area. The plot size was 3 × 4 m and the spacing between blocks and plots were 2 m and 1 m respectively.

Table 1. Soil physio-chemical characteristics of Hamedo irrigation scheme

Depth	Sand	Silt	Clay	Texture	PH	OM	EC	BD	FC	PWP	TAW
cm	**%**	**%**	**%**	**-**	**- -+**	**%**	**ds/m**	**g/cm3**	**vol.%**	**vol.%**	**mm/m**
0-30	40	34	25	loam	8.3	1.27	0.77	1.27	25.2	10.4	148.0
31-60	43	30	27	clay loam	8.6	1.20	0.97	1.35	27.3	11.2	161.0
Average	42	32	26	loam	8.5	1.24	0.87	1.31	26.3	10.8	154.5

OM=Organic matter, EC= Electrical conductivity, BD=Bulk density, TAW= Total available water

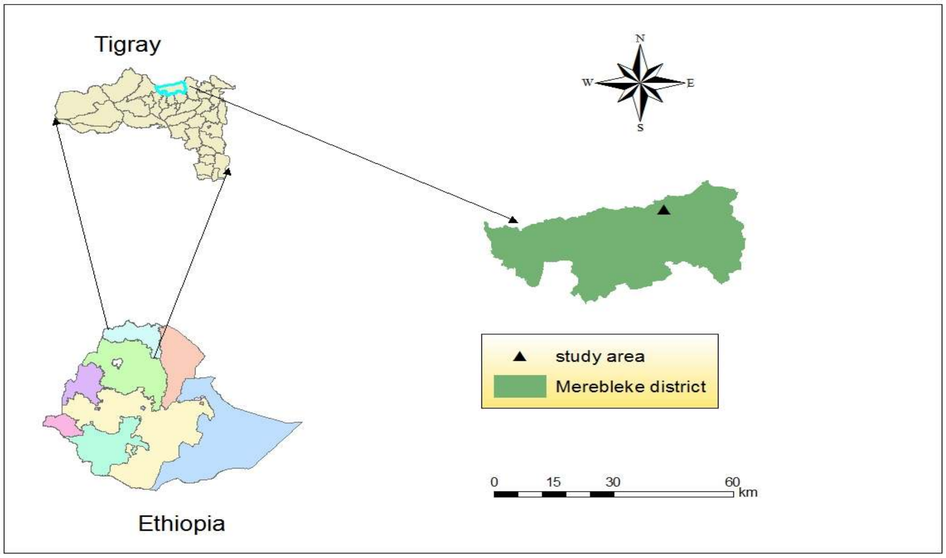

Fig. 1. Location map of the study area

Table 2. Treatment settings and their combination

Irrigation methods	Water level (%)	Treatments combinations	Treatment description
Conventional furrow irrigation (CFI)	100 % ETc	T1(CFI@100% ETc)	Conventional furrow irrigation with 100% crop water requirement
	80 % ETc	T2(CFI@80% ETc)	Conventional furrow irrigation with 80% crop water requirement
	60 % ETc	T3(CFI@60% ETc)	Conventional furrow irrigation with 60% crop water requirement
Alternate furrow irrigation (AFI)	100 % ETc	T4(AFI@100% ETc)	Alternate furrow irrigation with 100% crop water requirement
	80 % ETc	T5(AFI@80% ETc)	Alternate furrow irrigation with 80% crop water requirement
	60 % ETc	T6(AFI@60% ETc)	Alternate furrow irrigation with 60% crop water requirement

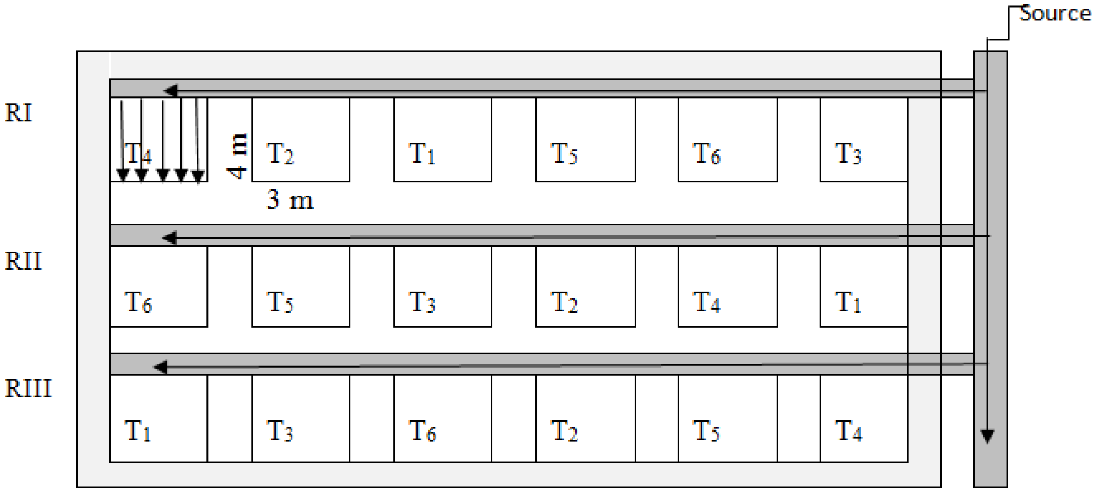

Fig. 2. Layout of the experimental plots

2.3 Experimental Management

The experiment was carried out in the dry season of November 21/2012 up to February 28/2013. Bombay red onion variety was used for the experiment as this variety is the most common crop in the study areas and the growing season of onion was mainly divided into four major growth periods [16]: initial, development, middle and late stages. Initial stage-runs from planting date to approximately 10% ground cover; development stage-runs from 10% ground cover to effective full cover; middle stage-runs from effective full cover to the start of maturity and Late stage-runs from start of maturity to harvest, or full senescence. Percent of ground cover and phenology of the crop was considered to decide the date of growth stages. Cultural management practices other than application of irrigation water were done according to the national recommendations. The experimental plot was ploughed three times before planting and weeds were controlled manually by hand. The application of fertilizer was based on the recommendations of AxARC i.e., DAP = 200 kg/ha, applied at transplanting and Urea = 100 kg/ha, applied half of it at transplanting and the remaining half after a month. The harvested yield was graded into marketable and non-marketable categories of onion bulb according to the size and degree of damage. Onion bulbs with less than 2 cm diameter were categorized under non-marketable [17]. The degree of damage were determined subjectively by observing the level of visible mould growth, decay, shriveling of bulbs.

2.4 Crop Water Requirement and Crop Water Productivity

The reference evapotranspiration (ETo) was estimated using the CROPWAT computer program or FAO Penman-Monteith equation [18] using the meteorological data collected from a nearby weather station. The crop water requirements (ETc) over the growing season were determined by multiplying the ETo values with the crop coefficients (Kc) given by [18]. Irrigation interval was 7-day and the amount of water for each irrigation event was determined based on eq.1

$$ETc = Kc*ETo \tag{1}$$

where ETc is the crop water requirement, Kc is the crop coefficient and ETo is the reference evapotranspiration. Irrigation scheduling of the crop was computed using FAO CROPWAT model [18] by considering the crop water requirement of onion and soil type of the experimental site with fixed interval (7 days) and variable depth (refill to field capacity). Since there was no rainfall during the experimental period, net irrigation requirement was taken to be equal to ETc. Besides, for 100% crop water requirement the value of ETc is equals to ETa. But for the other deficit levels the values of ETa is equal to ETc values times deficit percentage.

The optimum water requirement of onion for full irrigation application was computed for the

Table 3. Crop water requirement and irrigation water applied (mm) to each treatments

Treatments	CWR	E. Rainfall	NIR	GIR
T1(CFI@100%ETc)	352.6	0.0	352.6	587.7
T2(CFI@80%ETc)	281.1	0.0	281.1	468.5
T3(CFI@60%ETc)	209.6	0.0	209.6	349.3
T4(AFI@100%ETc)	176.3	0.0	176.3	293.9
T5(AFI@80%ETc)	140.6	0.0	140.6	234.3
T6(AFI@60%ETc)	104.8	0.0	104.8	174.7

CWR=Crop water requirement, E. Rainfall = Effective rainfall, NIR= Net irrigation water requirement, GIR= Gross irrigation water requirement

growing season of 95 days and the amount of water to other treatments was taken simply as percentage of the optimal irrigation at specific growth stage. The amount of water applied to both CFI and AFI treatments per furrow was the same. The difference is that AFI treatment received irrigation water alternately (some furrows received water at an irrigation event but others not) whereas for CFI treatments water was applied to the all furrows in the plot at each irrigation event. The seasonal amount of water applied was as shown in Table 2. The source of water for this experiment was from shallow well ground water and the quality irrigation water expressed as the electrical conductivity (EC_w) was found to be 0.48 dS/m which is save to use for irrigation as it is in the range between 0.250 and 0.75 dS/m [19].

Crop water productivity or water use efficiency was calculated [20] as:

$$WUE = Y/ ETa \quad (2)$$

where Y is the crop yield (kg/ha) and ETa is the actual evapotranspiration (mm) which was calculated based on the seasonal amount of water applied for each treatments.

Net return (NR) and benefit-cost ratio (BCR) due to irrigation were calculated according to [21,12] as follows:

$$NR = \text{Gross revenue} - \text{Total costs} \quad (3)$$

$$BCR = NR/\text{Total costs} \quad (4)$$

Data was subjected to statistical analysis using SAS 9.1 software and analysis of variance (ANOVA) was performed to evaluate the statistical effect of treatments. Least Significant Difference (LSD) test at probability level ($P \leq 0.05$) was also used to test any significant difference between treatment means.

3. RESULTS AND DISCUSSION

3.1 Yield and Water Use Efficiency of Onion

The analysis of variance (Table 1) indicated that the yields were statistically significantly ($p < 0.05$) affected by the amount of irrigation water applied. The maximum bulb yield was found in T1 (22.9 ton/ha) when full irrigation i.e. 100 % of ETc was applied under CFI. Whereas minimum yield of onion was obtained under the fully stressed treatment T6 (10.7 ton/ha). There was no significant different between the yield of T1 (22.9 ton/ha) and T2 (22.2 ton/ha) in spite of the fact that it was stressed by 20% throughout the growing season. Similarly, T4 (100% ETc under alternate furrow irrigation method) maintained similar yield (20.8 ton/ha) while there is a 50% reduction in irrigation water. This finding is also supported by the outcomes obtained by different researchers [8,13,11] who reported that alternate furrow irrigation can improve water use efficiency of crops and save irrigation water (30-50%) without significant yield reduction as compared to conventional furrow irrigation. Other previous studies [6,22,23], also revealed that there were no significant differences in yield between alternate furrow irrigation and conventional furrow irrigation even if less amount of water was used by the alternate furrow irrigation treatment.

Similarly, water use efficiency significantly influenced ($P < 0.05$) by the irrigation practices in combination with deficit irrigation applied in onion production. The highest WUE (7.43 kg/m^3) was obtained by AFI at 80% ETc followed by AFI at 100% ETc (7.12 kg/m^3) and the minimum (3.9 kg/m^3) was obtained by CFI at 100% ETc. These results indicated that AFI is appropriate to increase WUE of onion because they allow applying less irrigation water for onion production. The high WUE values for AFI could be due to the small amount of water applied for AFI as compared with the CFI treatment. AFI at different water levels has also indicated better performances in terms of WUE. Moreover, the amount of water saved in AFI without significant yield reduction (8.7%) was about 293.9 mm as compared to CFI. This shows that the plots under AFI used about 50% the amount of water compared to the plots under CFI. This reduction of water in AFI was a result of irrigating only alternate furrows, which would have also reduced evaporation and deep percolation losses. This may be due to the higher movement of water laterally than vertically which may not be seen in CFI because of the wetted sides of all furrows. Similar results have been also reported by [9,10]. [13] also reported that alternate furrow irrigation showed 5.5% yield reduction with 50% irrigation water. Similarly, other researchers such as [24] concluded that compared to conventional furrow irrigation, alternate furrow irrigation is a practical way to improve fruit quality and water use efficiency for irrigated crops in arid areas.

3.3 Economic Analysis of Conventional and Alternate Furrow Irrigation

The economic benefits were higher in CFI than AFI regardless of the higher cost in pumping and labor. The maximum BCR was 4.8 obtained from T_1 (application of 100% ETc @ CFI), followed by 4.7 from T_2 (application of 80% ETc @ CFI), whereas the minimum was 1.8 and 2.7 observed with T_6 and T_3 respectively (Table 3). The maximum NR was 94678.3 birr/ha as obtained from T_1, compared to the other treatments. Similar results were also reported by [11] who reported that AFI resulted in 9% less income than CFI. However when we compare them in terms of water saving and the potential of expanding the irrigable land, AFI can increase the yield and income of a farmer roughly by 45.4 and 34% respectively. These results indicated that if there is no scarcity water and the costs associated with delivery water to the field does not require additional expense, the full application of CFI treatment is essentially the best choice under the conditions of the study area. However, in case of limited water resource and high cost of pumping and labor, AFI gives much higher economic benefits because AFI can minimize costs associated with labor and pumping by 42.6% as compared to CFI. This result is in agreement with previous study by [23] who concluded that under limited irrigation water alternate furrow irrigation can be successfully used as an effective low cost substitute of normal furrow irrigation. Therefore, the preference between AFI and CFI depends on the availability of water and costs associated with pumping and labor in relation to crop returns.

Table 4. Mean effect of water application techniques on yield, yield reduction and amount of water saved

Treatments	MY (t/ha)	WUE (kg/m^3)	YR (%)	Water saved (m3/ha)	PEIL (%)	PYI (ton/ha)
T_1	22.9^{a}	3.90^{c}	0.0	0.0	0.0	0.0
T_2	22.2^{a}	4.73^{cb}	3.1	1192	25.0	5.5
T_3	14.6^{b}	4.19^{c}	36.2	2384	68.0	9.9
T_4	20.9^{a}	7.12^{a}	8.7	2938.5	100.0	20.8
T_5	17.4^{b}	7.43^{a}	24.0	3534.5	151.0	26.1
T_6	10.6^{c}	6.09^{ba}	53.7	4130.5	236.0	25.0

MY=marketable yield, YR= yield reduction, VAW= volume of applied water. PEIL = Possible expansion of irrigable land, YI= Possible yield increment due to the expanded area

Table 5. Economic analysis showing the benefits obtained with the adopted irrigation treatments

Treatment	CWA	TC	GI	NR	BCR
	birr/ha	**birr/ha**	**birr/ha**	**birr/ha**	**birr/ha**
CFI@100%ETc	587.7	19821.7	114500.0	94678.3	4.8
CFI@80%ETc	468.5	19577.7	111000.0	91422.3	4.7
CFI@60%ETc	349.3	19477.7	73000.0	53522.3	2.7
AFI@100%ETc	293.9	19215.9	104000.0	84784.2	4.4
AFI@80%ETc	234.3	19129.9	87000.0	67870.2	3.5
AFI@60%ETc	174.7	19043.9	53000.0	33956.2	1.8

AW= Applied water, CAW= Cost of applied water, TC= Total costs, GI= Gross income, NR= Net return and BCR= Benefit Cost Ratio

4. CONCLUSION AND RECOMMENDATIONS

Alternate furrow irrigation can be used as an efficient method in the semi-arid areas Tigray, northern Ethiopia as it is easy to apply (farmers friendly). The experimental results on alternate furrow irrigation for onion production revealed that this method can maintained similar yield (20.8ton/ha) with up to 50% water reduction (saving) compared with CFI (22.9 ton/ha). Similarly, it can drastically improve onion water productivity (7.12 kg/m^3) as compared to CFI (3.9 kg/m^3) and can be used as a practical water management practices to save water and thereby to expand irrigable areas. In addition to water saving and water productivity, AFI can also minimize costs associated with labor and pumping (fuel) by 42.6% as compared to CFI. Moreover, AFI increases the irrigable area, production and net income by 50, 45.4 and 34% respectively, whereas CFI increases the benefit cost ratio (4.8) and net return (94678 birr/ha) of farmers as compared to AFI but with no water saving. Therefore, the preference between AFI and CFI depends on the availability and value of water in relation to crop returns. Hence, it is recommended that if the cost of pumping is high and amount of available water is scarce, then the alternate furrow irrigation with 100% ETc will essentially be the best choice under the conditions of the study area and other similar agroecology areas.

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COMPETING INTERESTS

Author has declared that no competing interests exist.

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