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Effect of Deficit Irrigation on Yield and Water Use Efficiency of Maize at Selekleka District, Ethiopia

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ABSTRACT

Irrigation water availability is diminishing in many areas of the Ethiopian regions, which require many irrigators to consider deficit-irrigation strategy. This study investigated the response of maize (*Zea mays* L.) to moisture deficit under conventional, alternate and fixed furrow irrigation systems combined with three irrigation amounts over a two years period. The field experiment was conducted at Selekleka Agricultural Research Farm of Shire-Maitsebri Agricultural Research Center. A randomized complete block design (RCBD) with three replications was used. Irrigation depth was monitored using a calibrated 2-inch throat Parshall flume. The effects of the treatments were evaluated in terms of grain yield, dry above-ground biomass, plant height, cob length and water use efficiency. The two years combined result indicated that net irrigation water applied in alternate furrow irrigation with full amount irrigation depth (100% ETc AFI) treatments was half (3773.5 m^3/ha) than that of applied to the conventional furrow with full irrigation amount (CFI with 100% ETc) treatments (7546.9 m^3/ha). Despite the very significant reduction in irrigation water used with alternate furrow irrigation (AFI), there was insignificant grain yield reduction in maize(8.31%) as compared to control treatment (CFI with100% ETc). In addition, we also obtained significantly ($p<0.001$) higher crop water use efficiency of 1.889 kg/m^3 in alternate furrow irrigation (AFI), than that was obtained as 0.988 kg/m^3 in conventional furrow irrigation (CFI). In view of the results, alternate furrow irrigation method (AFI) is taken as promising for conservation of water (3773.5 m^3/ha), time (23:22'50" hours/ha), labor (217.36 USD/ha) and fuel (303.79 USD/ha) for users diverting water from the source to their fields using pump without significant trade-off in yield.

Keywords: Grain yield, water use efficiency, alternate furrow irrigation, deficit irrigation

INTRODUCTION

In Ethiopia,the traditional small-scale irrigation schemes in general are simple river diversion (Awulachew et al 2007). The diversion structures are elementary and subjected to frequent damage by flood. Modern irrigation was started at the beginning of the 1960s by private investors in the Middle Awash Valley of Ethiopia where big sugar estates, fruit and cotton farms are found (Steduto et al 2012).

The need for developing an irrigation system for crop production is getting more and more attention in Ethiopia in response to the growing demand for agricultural produce. Before 1974, private capital investment in agriculture has been increasing due to the government's policy encouraging the development of commercial farms in meagerly populated lowland areas of the country. The military government nationalized the rural lands and commercial farms together with newly established ones (mainly rain-fed ones) into state-owned enterprises (Fekadu et al 2000).

Ethiopia comprises of 112 million hectares (M ha) land area. Cultivable land area estimates between 30 to 70 M ha. Currently, an estimate of about 15 M ha of land is under cultivation. For existing cultivated areas, only about 4-5 percent is irrigated; with existing equipped irrigation schemes covering about 640,000 hectares. These irrigation schemes vary widely in size and structure, from micro-irrigation scale (rainwater harvesting) to large scale (river diversion, pumping and small or large dams) (Awulachew et al 2010). Based on data from the International Water Management Institute (IWMI) in Awulachew et at (2007), from a total of 640,000 hectares of irrigation nationwide; 128,000 hectares fall under rainwater harvest, 383,000 hectares under small scale irrigation and 129,000 hectares under medium to large scale irrigation system.

In Ethiopia, irrigation development is increasingly implemented more than ever to supplement the rain-fed agriculture but due to the development of other water use sectors as well as increasing concerns for environment water has become increasingly a scarce resource. This water shortage has motivated some researchers and farmers to find ways to produce a crop with less irrigation water and changing from fully-irrigated to deficit irrigated cropping system (Awulachew et al 2007). Deficit irrigation has been widely investigated as a valuable and sustainable production strategy in arid and semi-arid regions. It is one of the ways of maximizing water use efficiency (WUE) for higher yields per unit of irrigation water applied (Kirda 2002). Many research findings on deficit irrigation have shown that there are slight maize yield and yield component reduction.

Different works have been done on maize moisture deficit based on decreasing the depth of irrigation water. However, much work has not been done to determine the effect of double deficit irrigation strategy like partial root-zone drying in combination with decreasing depth of irrigation amount. Therefore, considering the scarcity of irrigation water, this research was aimed 1) to examine the effect of irrigation levels on the yield and water use efficiency of maize 2) to investigate the effect of furrow irrigation methods (alternate, fixed and conventional furrow) on yield and water use efficiency of maize 3) To evaluate the double deficit (irrigation levels and furrow methods) irrigation strategy on yield and water use efficiency of maize.

METHODS AND MATERIALS

General Description of the Experimental Area

This experiment was conducted at Selekleka Agricultural Research farm of Maitsebri Agricultural Research Center in 2017 and 2018 off-season time. The site is located in the Northern part of Tigray, Ethiopia at about 38.72°E longitude and 14.3°N latitude and at an altitude of 1782m above mean sea level. The long term mean monthly maximum and minimum temperature is 26.9°C and 11.2°C respectively. The average annual rainfall in the area is 678.32 mm characterized by mono-modal type with rainy seasons from June to September. The soil of the area is characteristically well-drained, light to dark brown in color and deep in depth, loamy sand in texture and continuously cultivated. The field capacity, permanent wilting point moisture content and available water holding capacity per meter of the soil profile in the root zone is 38.6%, 29.8% and 145.28 mm respectively.

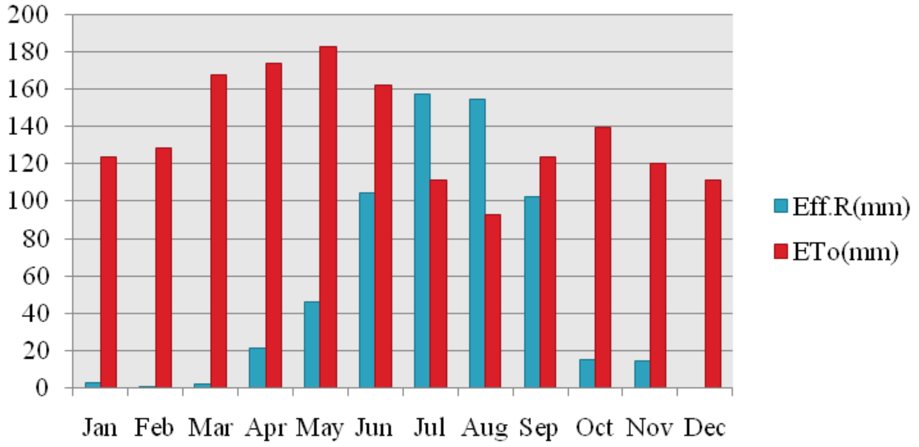

Figure 1. Monthly effective rainfall (Eff.R) as compared with reference evapotranspiration (ETo).

Treatments, Experimental Design and Management

The experiment was designed as a two-factor factorial experiment in a randomized complete block (RCBD) with three replications. The two factors were furrow irrigation systems and irrigation application levels. The treatments were three furrow irrigation systems; Alternate Furrow Irrigation (AFI), Fixed Furrow Irrigation (FFI) and Conventional Furrow Irrigation (CFI) and three levels of irrigation applications (**Table** 1). Each experimental plot had an area of 8.4 m^2, which consists of 4 furrows with 70 cm width and 3 m length. The recommended spacing of 30 cm between plants was employed. The spacing between blocks and experimental plots was 2 m and 1.5 m, respectively. Irrigation water was delivered to each plot using calibrated 2-inch Partial flume according to the treatments. Each experimental treatment was fertilized with an equal recommended fertilizer application, which was 200 kg/ha DAP and 150 kg/ha urea. The full dose of DAP was applied at the time of planting whereas urea was applied by splitting into two parts, half during planting and the rest just at 30 days after planting considering the size of the plots. All other cultural practices were applied uniformly to all plots as per the standard recommendations of the crop.

Table 1. Treatment set-up

Treatment Code	Treatment combination
T1	Alternate Furrow(AF) Irrigated at 100%ETc
T2	Alternate Furrow(AF) Irrigated at 75%ETc
T3	Alternate Furrow(AF) Irrigated at 50%ETc
T4	Fixed Furrow(FF) Irrigated at 100%ETc
T5	Fixed Furrow(FF) Irrigated at 75%ETc
T6	Fixed Furrow(FF) Irrigated at 50%ETc
T7	Conventional Furrow(CF) Irrigated at 100%ETc
T8	Conventional Furrow(CF) Irrigated at 75%ETc
T9	Conventional Furrow(CF) Irrigated at 50%ETc

Alternate furrow irrigation (AFI) meant one of the two neighboring furrows was alternately irrigated during consecutive irrigation events. Fixed furrow irrigation (FFI) meant that irrigation fixed to one of the two neighboring furrows. Conventional furrow irrigation (CFI) or traditional irrigation meant irrigating all furrows during consecutive watering. Where, full irrigation (100% crop water requirement) implies the amount of irrigation water applied as estimated using Penman Monteith with CROPWAT computer program and 75% ETc and 50% ETc irrigation level meant 25% and 50% less of full irrigation requirement respectively.

Test crop Characterization

The test crop used in this study was BH-545 improved variety of maize (*Zea mays* L.) with a growing period of 110-120 days in the study area. The crop was sown on 15th December 2017 and 20th December 2018 offseasons. Maize seeds were sown by hand in a plot size of 3 m by 2.8 m. Hence, there were a total of four handmade furrows within a plot and 30 seeds within a single furrow. The spacing of 1.5 m between plots within a block and 2 m between blocks were used. The spacing used within a single furrow and between furrows within a single plot was 30 cm and 70 cm, respectively. In addition, plant parameters such as rooting depth and stages of growth were taken from Maitsebri Agricultural Research Center, Crop research Core Process. The other crop characteristics such as maximum rooting depth, crop coefficient and maximum allowed depletion level were taken from the Food and Agriculture Organization (Steduto et al 2012). According to FAO irrigation and drainage paper (Allen et al 1998), maximum root depth of 90cm; crop coefficient of 1.15 and allowed depletion level value of 0.55 were used in the determination of crop water requirement.

Crop water requirement and Irrigation Schedule

The estimate of the water requirement and irrigation scheduling of crops under this study is based on the atmospheric conditions of the environment by using a model. A computer program called “CROPWAT version 8.0” was used to determine reference evapotranspiration, crop water requirements, and irrigation schedule by utilizing metrological data as an input. For estimation of water irrigation requirements, climatic, crop and soil data have been utilized as an input. This calculation has been done by using the FAO Penman-Monteith method (Aallen 1998). In this experiment, the reference evapotranspiration (ETo) and crop water requirement (ETc) were estimated from long term climatic data collected from Maitsebri first-class Metrological station 1km far from the experimental station.

Data Collection

Climatic data: Before the start of the experiment, secondary data such as climatic data of 20 years on rainfall (R.F.) min and max temperature, relative humidity (RH), wind speed (WS) and sunshine hours (SH) were collected from the nearby meteorological station. Irrigation efficiency for furrow irrigation, root depth of maize crop, maize crop growth stages and their respective length of period and soil infiltration rate data were also collected from previous records and FAO guidelines.

Soil Physical Properties: Three soil profiles were randomly made in the experimental site to measure soil physical properties. Soil texture was determined using the pipette method (Gee and Bauder 1986) at 0-25, 25-50, 50-75 and 75-100 cm depths for each of the three soil profiles. Bulk density was determined by the core method (Blake and Hartage 1986) for each depth in the three profiles. Soil water content was determined from soil samples taken at the same locations using the gravimetric method. Field capacity and permanent wilting points were considered at 0.3 and 15.0 bars, respectively (Klute 1986). The soil basic infiltration rate was determined in the field using double-ring infiltrometer method in two separate sites in the experimental area as described by (Bouwer 1986) (**Table 2**).

Table 2. Soil physical properties of the experimental site

Soil properties	**Soil depth (cm)**				
	0-25	**25-50**	**50-75**	**75-100**	**Average**
Particle size distribution					
- Sand (%)	60	56	54	56	56.5
- Clay (%)	16	18	18	18	17.5
-Silt (%)	24	26	28	26	26
-Textural Class	Sandy Loam	Sandy Loam	Sandy Loam	Sandy Loam	Sandy Loam
Bulk density (g/cm^3)	1.38	1.34	1.33	1.31	1.34
Field capacity (weight basis %)	30.3	37.8	38.9	38.6	36.4
Permanent wilting point (weight basis %)	24.8	22.2	25.3	29.8	25.53
Total available water (mm/m)					**145.28**

Grain Yield and Yield Components

Grain yield, above-ground dry biomass yield data, were collected from the central quadrant plot size of 4.2m^2 and extrapolated to a hectare basis. Plant height and cob length were collected from six plant samples randomly selected from the two central furrows and averaged to get the average value in plant height and cob length. Days to 50% silking and 50% anthesis, was observed when 50% of the plants emerge silk and anthesis respectively.

Water-use efficiency (WUE)

The term water use efficiency is used to describe the relationship between growth (particularly dry matter production) and water use (Oweis and Zhang 1998). Water use efficiency (WUE) is expressed as a yield per unit of water used by the plant. The total seasonal amount of water used by the crop per treatment was recorded and the crop water use efficiency (kg/m^3) for each treatment was calculated as the ratio of grain yield (kg) to total seasonal irrigation water consumption (m^3).

Data Analysis

Analysis of variance was performed following the procedures of Freeman, Gomez and Gomez (1985) using Gen Stat statistical software. Treatments showing significant differences were subjected to Duncan’s multiple range test (DMRT) for mean separation at a 95% confidence level.

RESULTS

Water Consumption and Irrigation Demand

Maize variety BH-545 was planted on 15 December 2017 and 20 December 2018 off-season time. Total precipitation during the months of December to May in both years was insignificant. As a result throughout the growing period of the test crop, the only source of water was irrigation. Totally, 14 irrigation events were adopted during the crop growing period. The amount of net applied irrigation water according to treatments is presented in **Table 3**.

Table 3.Total seasonal net irrigation depth applied to treatments

S.№	Treatments	Net irrigation depth (mm)
1	CFI100%ETc	754.69
2	AFI/FFI 75%ETc	283.11
3	CFI 50%ETC,AFI/FFI 100%ETc	377.35
4	CFI75%ETc	566.23
5	AFI/FFI 50%ETc	188.83

AF = Alternate furrow irrigation; FFI= fixed furrow irrigation; CFI= Conventional furrow irrigation and ETc = Crop evapotranspiration

Based on the output of the CROPWAT 8 model, the optimum seasonal irrigation requirement in the area for maize was found to be 754.69 mm (7546.9 m^3/ha) for conventional furrow irrigation method (**Table 3**). Similarly, for the alternate furrow irrigation (AFI) and fixed furrow irrigation (FFI), 377.35 mm (3773.5 m^3/ha) of water was needed throughout the growing season at full crop evapotranspiration (100%ETc). As presented from **Table 3** the alternate furrow and fixed furrow irrigation treatments at optimum crop water requirement (100%ETc) consumed less water as compared to conventional furrow irrigation method.

The seasonal amount of water consumed by the alternate furrow irrigation and conventional furrow irrigation under full crop water requirement (100%ETc) were amounted to be 377.35 mm (3773.5m^3/ha) and 754.69 mm (7546.9 m^3/ha) respectively. According to the FAO guidelines, the approximate value of seasonal crop water requirement of maize for maximum yields is 500 to 800 mm depending on climate (Critchley and Siegert 1991). The amount of water applied for conventional furrow irrigation treatment was agreed with the range of water requirements stated above. Amount of water applied under alternate furrow irrigation also agrees with the conclusion that says that alternate furrow irrigation is commonly applied as part of a deficit irrigation program because it does not require the application of more than 50–70% of the water used in a conventional furrow irrigation method (Webber et al 2006). On the other hand, alternate furrow irrigation technique recorded lower values of total evapotranspiration as compared to conventional furrow irrigation technique. This may be due to the half irrigation of the planting area, and the fact that the root absorbed water only from some parts of the soil (Barideh et al 2018). **Table 3** indicates that alternate furrow and fixed furrow irrigation technique saved 50% of irrigation water as compared to conventional furrow irrigation technique at full irrigation requirements (100%ETc).

The lowest depth of water applied under alternate furrow irrigation method as compared to conventional furrow irrigation is a result of a great reduction of wetted surface. This result supports the outcome obtained by the study that concludes alternate furrow irrigation method which can supply water in a way greatly reduces the amount of wetted surface, which leads to less evapotranspiration and less deep percolation (Shayannejad and Moharreri 2009)

Yield and Growth Parameters

Plant Height and Cob length: The two years over year statistical analysis showed that plant height and cob length of maize had not affected by the application of different irrigation levels ($p<0.05$). However, as the deficit irrigation level increases the plant height decreases as indicated from **Table 4**. Similar research findings as in the case of (Rosadi et al 2005) discovered that a small difference in moisture deficit levels did not affect plant height. Our research finding is also similar to a research finding done on Bulga-70 common Bean cultivar said that plant height is not statistically different for 100, 75 and 50% of crop evapotranspiration (Molla and Abiot 2018). In this experiment, we had not observed the combined influence of irrigation levels and furrow methods on plant height of maize crop (**Table 4**). However, the application of different furrow irrigation methods significantly influenced pant height and cob length of maize production.

Table 4. Analysis of variance on important agronomic parameters of maize (2017/2018)

Source of Variation	Plant Height	Cob length	Grain yield	AGBY	WUE
Irrigation Levels	NS	NS	***	***	**
Furrow Methods	**	**	***	***	***
Irrigation ×Furrow	NS	***	***	*	*

*NS=Not significant; *, **, *** indicates significant at 0.05, <0.01) and <0.001) levels respectively; ABGY= above-ground dry biomass yield; WUE = Water use efficiency*

The highest in plant height (1.76 m) and cob length (18.30 cm) was produced under conventional furrow irrigation method, whereas the lowest in plant height (1.48 m) and cob length (15.54 cm) was obtained from fixed furrow irrigation method (Table 5). As seen from Table 4, the combined effect of irrigation levels and furrow methods had observed very highly significant (p< 0.001) on cob length of maize.

Table 5. Statistical comparison of the mean values of relevant parameters of maize (2017/2018)

Source of Variation	PH (m)	CL (cm)	Gyld (kg/ha)	AGBY (t/ha)	WUE (kg/m3)
Irrigation levels (%ETc)					
100%ETc	1.66^{a}	16.59^{a}	5704.8^{a}	15.05^{a}	1.188^{b}
75%ETc	1.64^{a}	16.12^{a}	4583.9^{b}	11.06^{b}	1.311^{b}
50%ETc	1.62^{a}	16.01^{a}	3663.2^{c}	10.86^{b}	**1.584^{a}**
LSD (α=5%)	0.12	1.10	661.9	1.325	**0.262**
P-Value	0.232	0.085	**<0.001**	**<0.001**	**0.005**
Furrow Irrigation Methods					
Conventional	**1.76^{a}**	**18.30^{a}**	**5531.5^{a}**	**15.28^{a}**	0.988^{b}
Alternate	1.612^{c}	16.12^{b}	**5190.3^{a}**	11.81^{b}	**1.889^{a}**
Fixed	1.480^{b}	15.54^{b}	3229.7^{b}	9.89^{c}	1.206^{b}
LSD (α=5%)	0.12	1.10	661.9	1.325	0.262
P-Value	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Furrow Methods ×Irrigation levels (%ETc)					
Alternate furrow and 100%ETc	1.469^{a}	14.43^{cd}	6714.8^{a}	14.18^{b}	1.778^{b}
Conventional furrow and 100%ETc	1.795^{a}	20.83^{a}	7323.3^{a}	19.69^{a}	0.972^{cd}
Fixed furrow and 100%ETc	1.720^{a}	16.70^{bc}	3075.2^{ef}	11.29^{cde}	0.815^{d}
Alternate furrow and 75%ETc	1.572^{a}	16.77^{bc}	4548.6^{bcd}	10.63^{de}	1.607^{b}
Conventional furrow and 75%ETc	1.695^{a}	17.57^{b}	5238.2^{bc}	13.48^{bc}	0.925^{d}
Fixed furrow and 75%ETc	1.619^{a}	17.77^{b}	3964.5^{de}	9.07^{e}	1.400^{bc}
Alternate furrow and 50%ETc	1.405^{a}	14.43^{d}	4310.8^{bcde}	10.62^{de}	2.288^{a}
Conventional furrow and 50%ETc	1.790^{a}	16.50^{bc}	4032.3^{cde}	12.65^{bcd}	1.068^{cd}
Fixed furrow and 50%ETc	1.491^{a}	13.90^{d}	2647.5^{f}	9.31^{e}	1.402^{bc}
LSD (α=5%)	0.204	1.904	1146.4	2.296	0.454
P-Value	0.203	**<0.001**	**<0.001**	**0.035**	**0.031**
Mean	1.62	16.65	4650.3	12.33	1.361
CV (%)	10.7	9.6	20.5	16.0	25.7

PH= Plant height; CL= Cob length; Gyld =Grain yield; AGBY= above ground dry Biomass yield; WUE = Water Use Efficiency and ETc = Crop evapotranspiration

Grain Yield and above Ground dry biomass Yield

The two years' statistical combined analysis indicated a very high significance influence (p<0.001) due to the adoption of both different furrow irrigation methods as well as irrigation levels on grain and above-ground dry biomass yield (Table 4). The interaction effect of irrigation deficit levels and furrow methods is also very highly significant (p<0.001) on maize grain yield and significant (p<0.05) on above-ground dry biomass yield. The result revealed that conventional furrow irrigation with 100% crop evapotranspiration (ETc) gave the highest grain yield (7323.3 kg/ha) and dry biomass yield (19.69 t/ha) followed by alternate furrow irrigation with 100% crop evapotranspiration (ETc) to be 6714.8 kg/ha and 14.18 tons/ha respectively (Table 5). The minimum in grain yield (2647.5 kg/ha) and dry biomass yield (9.31t/ha) was obtained from fixed furrow irrigation at 50% of crop evapotranspiration (ETc). The major finding here is that irrigation water applied to alternate furrow irrigation method with 100%ETc is 50% less than that of applied to conventional furrow irrigation with 100% ETc and the yield reduction was

8.31%. This implies that applying alternate furrow irrigation will not produce significant yield reduction as compared with the conventional furrow irrigation method in terms of grain yield. While the above-ground biomass yield decreased significantly in alternate furrow irrigation compared to conventional furrow irrigation (**Table** 5). The highest (19.69 t/ha) and the lowest (14.18 t/ha) in dry above ground biomass yield were obtained from conventional and alternative furrow irrigation methods with 100%ETc respectively. Many researchers conducted research on deficit irrigation on different crop types such as (Jonghan and Piccinni 2009). (Simsek et at 2011) revealed that, as the moisture deficit level increased the production of crops will be declined which agreed with the current findings. Other reports conducted on soybean by Robel Admasu and Addisu Assefa (2019), Meskelu and Tesfaye (2018) and Mohammed and Kannan, (2015) on maize crop discovered that above-ground dry biomass yield is higher for conventional furrow irrigation system than alternate and fixed furrow irrigation methods which support our current findings.

Irrigation Water Savings

Water Use Efficiency (WUE): As indicated in **Table** 4, there was a significant difference due to the application of different furrow irrigation methods as well as irrigation deficit levels at 0.1% and 1% significant levels respectively on water use efficiency (WUE) of maize. The highest water use efficiency value was 1.889 kg/m^3 and 1.584 kg/m^3 obtained from the alternate furrow irrigation and 50% ETc treatments respectively whereas, the lowest value of 0.988 kg/m^3 and 1.188 kg/m^3 was obtained from conventional furrow irrigation and 100% ETc treatments respectively (**Table** 5). Therefore, the above data analysis showed an application of 50% ETc and alternative furrow (AF) perform well in accordance with water use efficiency of maize with saving of more water and no significant yield reduction. It will save 50% water applied as compared to the conventional furrow irrigation method and 100% crop evapotranspiration (ETc). This finding is similar to finding states that, applied water was used more efficiently in the alternate furrow irrigation treatment (Addisu Tadesse and Teshome 2018).

The higher mean value of water use efficiency obtained under alternate furrow irrigation was related to a lower amount of water applied with uniform lateral movement in crop root zone and minor grain yield reduction obtained under this method. The reason for better water use efficiency (WUE) and minor yield reduction for alternate furrow irrigation could be related to improve the lateral distribution of water in the root zone that increases water and fertilizer uptakes by the plant. This result indicates that alternate furrow irrigation is appropriate to increase water use efficiency by allowing to apply less irrigation water for maize production which supports the outcome of the study that says using alternate furrow irrigation can be produced higher water use efficiency (WUE) (Saeed and Grove 2008)

Additional Area Gained: **Table** 6 indicated that, amount of water saved under alternate and fixed furrow irrigation methods comparing with a conventional furrow. This table also indicated that additional area can be irrigated by the amount of water saved under alternate and fixed furrow irrigation methods. Alternate furrow irrigation and fixed furrow irrigation saved 377.34 mm (3773.4 m^3/ha) of water applied under conventional furrow irrigation method which can be used to irrigate oneha of additional land using alternate furrow or fixed furrow irrigation method for maize production. Moreover, applying alternate furrow irrigation method improved water use efficiency and saved 3773.4 m^3/ha (50%) of water consumed under the conventional furrow irrigation method. Alternate furrow and fixed furrow irrigation received the same amount of irrigation water, whereas low water use efficiency was obtained under fixed furrow irrigation compared to alternate furrow irrigation method. This result is similar to the finding in Jovanovic et al (2010) that alternate furrow irrigation increases water use efficiency as compared with fixed furrow irrigation techniques.

Generally, alternate furrow irrigation system increased water use efficiency (WUE) with minor or no yield reduction as compared to conventional furrow irrigation method. The finding of this study similar to the result of the studies that concluded alternate furrow irrigation increases water use efficiency with minor or no yield reduction and save a substantial quantity of irrigation water (Nouri and Nasab 2013).

Table 6. Irrigation water saved and the additional area gained under furrow irrigation treatments

Treatments	Irrigation water Consumed (m3/ha)	Irrigation water saved (m3/ha) Comparing with CFI	Additional area can be irrigated (ha)
AFI	3773.5	3773.4	1
FFI	3773.5	3773.4	1
CFI	7546.9	0	0

AFI, FFI and CFI, Alternate furrow irrigation, fixed furrow irrigation, and CFI, Conventional furrow irrigation respectively

DISCUSSION

In the study area, the depth of rainfall is low and its distribution is uneven and highly erratic to meet the daily crop evapotranspiration requirement. Under this condition, the need to use the available water economically and efficiently is indubitable. This study puts emphasis on the comparison of irrigation management strategies which could contribute to water-saving, increase water use efficiency with no or minimum yield reduction in the semi-arid climate of Northern Ethiopia particularly the Northwestern zone of the Tigray region. Results confirmed that different irrigation treatments significantly influenced yield, water use efficiency and other most parameters of maize. Statistically insignificant grain yield reduction was observed under alternate furrow irrigation method as compared with conventional furrow irrigation. The highest grain yield was obtained from conventional furrow irrigation followed by alternate furrow irrigation methods. The lowest grain yield was obtained from the fixed furrow irrigation method. Alternate furrow and fixed furrow irrigation methods saved 50% of the water applied under of conventional furrow irrigation method. However; under fixed furrow irrigation method low water productivity was recorded as compared with the alternate furrow irrigation method. This study promotes that alternate furrow irrigation was considerably saved water than conventional furrow irrigation method without significant yield reduction.

The results in this study verified that alternate furrow irrigation method is attractive in water use efficiency (WUE) as compared with conventional and fixed furrow irrigation methods. With alternate irrigation strategies, it is possible to increase water use efficiency and save significant depth of water for irrigation without significant yield reduction**.** From this result, one can conclude that applying alternate furrow irrigation method improved water efficiency by saving 50% of the water applied under conventional furrow irrigation method which is sufficient to irrigate 1 hectare of additional maize cropped land.

Therefore applying alternate-furrow irrigation with appropriate irrigation intervals is an efficient method in the study area where the soil is mainly dominated by sandy loam and water become a limiting factor in maize production. The predilection between alternate furrow irrigation method and other methods depends on the value of water and crop returns. This water application technique is much important in the study area in particular, in Ethiopia in general where a limited amount of water is available for irrigation and irrigation water management is very traditional.

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