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Evaluating the Effect of Alternate Furrow Irrigation on Yield and Water Productivity of Maize at Ambo, Ethiopia

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Abstract: Efficient use of water is a key factor for irrigation water management to increase water productivity and reduce the environmental impacts of irrigation. Thus, two field experiments were conducted to evaluate the performanceeffect of alternate furrow and regular deficit irrigation application levels on yield and water productivity of maize. Three furrow irrigation application methods (alternative furrow, fixed furrow and convectional furrow irrigation) with three deficit levels (100%, 75% and 50%of the full crop water requirement) were applied to select the best performing furrow irrigation based on water productivity of maize. This experiment designed as a two factor factorial experiment arranged in randomized complete block design having nine treatment combinations and replicate thrice. The over year analysis result showed that grain yield and water productivity of maize were influenced by both furrow application method and deficit level at $p < 0.05$. The overall mean result indicates that application of alternate furrow irrigation saves half of the total volume of water applied with 5.5% non-significant yield reduction and 47.5 % significant water productivity increment as compared to conventional furrow irrigation. Also application of regular deficit irrigation with three fourth of full irrigation enhance water productivity of maize by 20 % with 8.25 % non-significant yield reduction. Therefore from this experimental result shifting of conventional furrow irrigation to alternate furrow irrigation enhances water productivity of maize without a significant yield reduction, thus it is recommended to use this method for the study area.

Key words: Water productivity · Alternate furrow irrigation and Maize

INTRODUCTION

Maize (*Zea mays* L.) is one of the most important cereal crop grown worldwide with an essential nutritional component in human food and animal feed formulation [1, 2]. In theworld itsproduction ranks in third place following wheat and rice. Ethiopia is one of the largest maize producing countries in Africa and it is the leading crop produced by farming community with the highest area coverage next to teff [3].

According FAO [4] irrigated agriculture covers 40 % of global agricultural production and it is the largest is freshwater user on the planet, accounting for more than 75% of total withdrawals [5]. Increment in water demand due to climate change, rapid population growth and agricultural land expansion causes global water scarcity and it is the main constraint for crop production [6]. Thus irrigation water management practices will have to be carried out most efficiently to enhance water productivity of irrigated agriculture for ensuring food security.

Various water saving approaches have been proposed and developed to improve crop water productivity of different cropsat a field scale. Deficit irrigation (DI) systemsis one of the management practices that have been successfully implemented to improve water productivity of various crops [7]. In Deficit irrigation practices the crop is irrigated below its water requirement to improve water productivity at a certain degree of water deficitwithoutcausing severe yield reductions [8, 9]. Alternate furrow irrigation is novel deficit irrigation strategy that enhance water productivity by irrigating the furrow alternatively rather than irrigating every furrow at a time [9, 8]. According to Kang *et al*. [10] and Jarvis [11] this practices have appositive effect on water and nutrient uptake for plants. It reduced surface

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areas for soil water evaporation; increase the water uptake rate for the roots that have access to soil water to compensate for the roots that have little access to water (dry zone); stimulate the growth of secondary roots and increase root activity for improving uptake of mineral nutrients and enhancing nutrient recovery in plants.

Different researcher proved that alternate furrow irrigation as a water-saving technique to improve water productivity without a significant yield reduction. Kang *et al*. [10] Reported that AFI exhibited a reduction in irrigation water by 50% without significant variation on maize grainyield. Akbar, H. *et al.* [12] Also stated that application of alternative furrow irrigation is better solution for improving water productivity by saving 50% of the applied water with only 6.5% non-significant yield reduction of Sweet Corn as compared to conventional furrow irrigation. Result of Seid and Kannan Narayanan [13] on comparison of Alternate and conventional furrow on maize revealed that application of Alternate furrow irrigation save 50% of the applied water without a significant yield reduction of 5.58 %. A review on alternate partial root zone drying for diverse cropsrevealed that, it is a water saving irrigation strategy that can save up toapproximately 50% irrigation water without significant yield loss as compared to full irrigation application Sepaskhah & Ahmadi, [14] and Chai *et al*. [8].

Due to change in climate there is a spatial and temporal variability in rainfall throughout the country which affect the rain fed agriculture. Also the increasing demand for food due to a rapidly growing population require an urgent improvement of crop productivity per unit of water consumed in agriculture. Thus it is critically important to use more efficient irrigated agricultural practices to satisfy the food demand of the ever increasing population growth in the country.

The present experiment aimed to investigate the response maize to different irrigation levels under alternate fixed and conventional furrow irrigation; hypothesized that maize plants would respond better to alternate furrow irrigation, which ultimately improves water productivity for maize production.

MATERIALS AND METHODS

Description of the Study Area: The experimental study was conducted at Ambo Agricultural Research Center and the site is situated on 38° 07’N E longitude and 8° 57’N latitude and 2144 m.a.s.l altitude. The area experienced bimodal rainfall with a mean annual precipitation of 1029 mm. The mean maximum and minimum temperature of the area is 26.4°C and 10.3°C respectively. The soil texture of the experimental site has been classified as clay soil with 67.1%, 16.5 % and 16.4 % clay, silt and sand respectively.

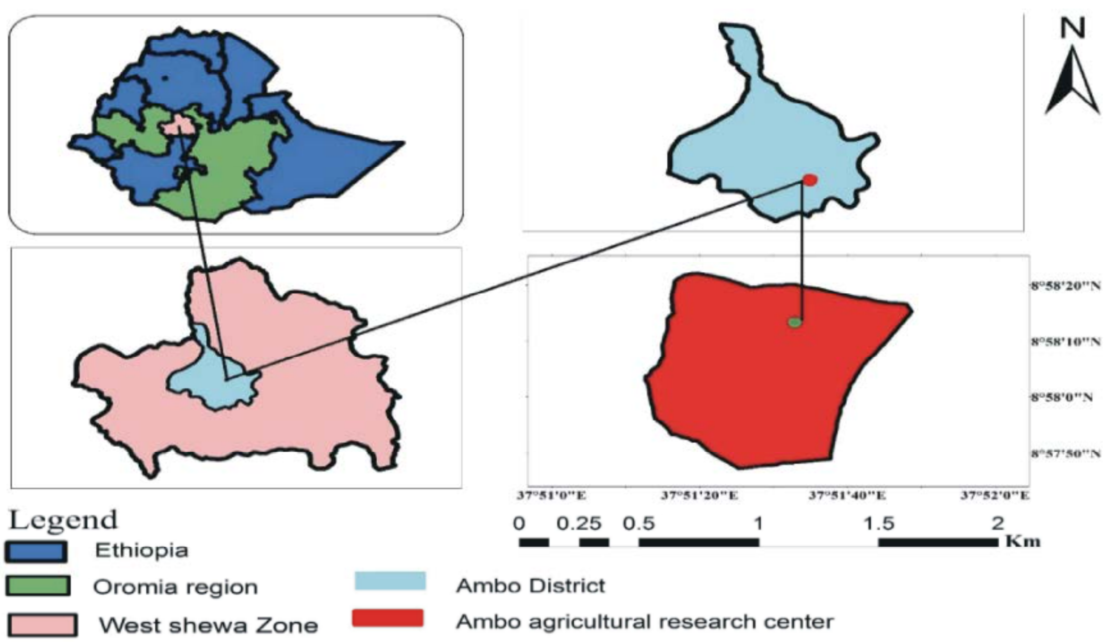

Fig. 2.1: Location Map of the study area

Experimental Treatment and Design: A field experiment was conducted at Ambo agricultural research center experimental site for two consecutive years (2018 and 2019) during the dry season. The experiment was laid out in randomized complete block design having two factors replicated thrice with a plot size of 4.5 m x 5 m. A buffer zone of 2 m was provided between each plotto avoid the effect of irrigation treatment. There were three irrigation treatments (no water deficiency treatment), 75% of full irrigation (25% deficit) and 50% of full irrigation (50% deficit) application levels respectively. The secondfactor comprised of three furrow application method (alternate furrow irrigation (AFI), fixed furrow irrigation (FFI) and conventional furrow irrigation (CFI)). Totally the experiment consists of three by three treatment setup having nine treatmentcombinations (Table 1).

Remark 1: Means of irrigation water application for each irrigation system were described under 2.4
The combined analysis was done.

Table 1: Combination of experimental treatments

Treatment	Combinations
T1 (AFI100%ETc)	Alternative Furrow Irrigation irrigated at 100% ETc
T2 (AFI 75%ETc)	Alternative Furrow Irrigation irrigated at 75% ETc
T3 (AFI 50%ETc)	Alternative Furrow Irrigation irrigated at 50% ETc
T4 (FFI 100%ETc)	Fixed Furrow Irrigation irrigated at 100% ETc
T5 (FFI 75%ETc)	Fixed Furrow Irrigation irrigated at 75% ETc
T6 (FFI 50%ETc)	Fixed Furrow Irrigation irrigated at 50% ETc
T7 (CFI 100%ETc)	Conventional furrow Irrigation irrigated at 100% ETc
T8 (CFI 75%ETc)	Conventional furrow Irrigation irrigated at 75% ETc
T9 (CFI 50%ETc)	Conventional furrow Irrigation irrigated at 50% ETc

Determination of Reference Evapotranspiration and Crop Water Requirement: Reference evapotranspiration (ETo) estimated by FAO Penman-Monteith method on the basis of the 20-year (1993–2014) metrological data from the study area meteorological station using decision support software COPWAT8.0 model developed by FAO. Meteorological data used for determination of ETo were latitude, longitude and altitude of the study area, maximum and minimum air temperature, air humidity wind speed, sunshine hour and radiation data as described in Table 2.

Crop water requirement to compensate the amount of water lostthrough evapotranspiration (ETc) over the growing season computed using CROPWAT software from reference evapotranspiration (ETo) and crop coefficient (Kc). Maize crop coefficient (Kc), length of growth stage and allowable soil moisture depletion level (p=0.55) values were obtained from irrigation and drainage paper (FAO 56) [15].

$$ET_c = ET_0 * K_c \qquad (2.1)$$

where,
ET_c = Crop evapotranspiration (mm d^{-1})
K_c = Crop coefficient (dimensionless) and
ET_o = Reference crop evapotranspiration (mm d^{-1})

The net and growth irrigation water requirementto satisfy the designed crop water requirement was computed with the aid of CROPWAT model [15] using necessary primary and secondary data on long term climatic data, soil data of the experimental site, test crop data irrigation efficiency of furrow irrigation and effective rainfall data using (2.2).

$$IR_n = ET_c - Pe \qquad (2.2)$$

where:
IR_n = Is net irrigation requirement (mm),
ET_c = Is crop evapotranspiration (mm) and
P_e = Effective rainfall (mm)

The gross irrigation requirements account for losses of water incurred during conveyance and application to the field. This is expressed in terms of efficiencies when calculating project gross irrigation requirements from net irrigation requirements using (2.3).

$$IR_g = \frac{IR_n}{Ea} \qquad (2.3)$$

where:
IR_g = Gross irrigation requirement (mm),
IR_n = Net irrigation requirement (mm)
E_a = Irrigation efficiency (%)

Experimental Procedure and Management Practice: In order to implement this experiment, the experimental plot of 4.5 m by 5m with 75 cm furrow spacing was prepared. One day before sowing the entire experimental plots were irrigated up to a field capacity and field capacity and Jibat variety was sown at 75 cm and 25 cm inter row and intra row spacing during the first week of November for two consecutive years. The entire plots were uniformly pre-irrigated prior to starting treatment applications in order to stabilize seed germination. A common recommended fertilizer rate for the study area was applied manually in the experimental plot. All plots received the same amounts of fertilizer consisted of 92 kg/ha Nitrogen from 200 kg/ha of urea and 30 kg/ha Phosphorus from 150 kg/ha of DAP, the total amount of DAP applied at planting while Urea applied in split form.

Table 2: 20 years monthly average climate data of the experimental site (1995-2014)

Month	Min Temp (°C)	Max Temp (°C)	Humidity (%)	Wind speed (Km/day)	Sun shine hours	Rad (MJ/m²/day)	ETo (mm/day)
January	9	27.1	56	2	4.1	13.9	2.42
February	10.2	28.2	49	3	4.5	15.4	2.73
March	11.5	29.2	50	3	4	15.4	2.92
April	11.5	28.5	54	2	3.6	15	2.91
May	11.2	28.1	59	2	6.2	18.6	3.44
June	11.2	25.9	68	1	2.7	13.1	2.6
July	10.8	24.2	79	1	1.8	11.9	2.38
August	10.4	23.5	81	1	1.8	12.1	2.37
September	10.2	24.5	74	1	2.6	13.3	2.53
October	9.2	25.7	63	2	4.5	15.5	2.79
November	8.7	25.9	58	2	4.6	14.7	2.56
December	8.3	25.9	58	2	4	13.4	2.31
Average	10.2	26.4	62	2	3.7	14.4	2.66

Table 3: Total water requirements (applied) for each treatment throughout crop growth

Treatments	Applied water (m³/ha)	Applied water (m³/plot)	Depth of water Applied (mm/plot)
AFI100%ETc	3844	8.649	384.4
AFI75%ETc	2883	6.48675	288.3
AFI50%ETc	1922	4.3245	192.2
FFI100%ETc	3844	8.649	384.4
FFI75%ETc	2883	6.48675	288.3
FFI50%ETc	1922	4.3245	192.2
CFI100%ETc	7688	17.298	768.8
CFI75%ETc	5766	12.9735	576.6
CFI50%ETc	3844	8.649	384.4

After irrigating the whole plot uniformly twice for seed germination, treatment application was started as per the calculated crop water requirement determined by CROPWAT8.0. In Alternate furrow irrigation application is alternating of the two neighboring furrows, which indicated that irrigation was carried out in 1, 3, 5 furrows at the first irrigating time and was carried out in 2, 4, 6 furrows at the second irrigation time. In the case of fixed furrow irrigation irrigating application carried out in 2, 4, 6 furrows throughout the irrigation application time while in the case of conventional furrow irrigation, irrigation application carried out at every furrow. Soil moisture content was monitored using gravimetric method and amount of irrigation water at each irrigation application time were applied by measuring through Parshall flume. All other management practices were applied uniformly for all treatments as per the requirement.

Data Collection and Analysis

Yield and Yield Component Data: Maize grain yield, dry biomasswas collected from the four central rows by omitting two plants at both sides of these rows in order to minimize border effect. Other yield component data were collected from five plants selected at central row.

Water Productivity and Yield Response Factor: Water productivity (WP) is generally defined as yieldper unit of irrigation water applied [16]. Thus, in this study, the water productivity was determined by dividing the grain yield ofmaize to the amount of water consumptively used by the crop using (2.4).

$$Water\ productivity\ (WP) = \frac{Grain\ yield}{Growth\ irrgation\ applied} \quad (2.4)$$

Data Analysis: Data were subjected to analysis of variance (ANOVA) using SAS computer program. The Least Significant Difference (LSD) test was applied at 5 % level of significance to compare means among the treatment.

RESULT AND DISCUSSION

Influence of Regular Deficit and Alternate Furrow Irrigation on Grain Yield of Maize: The two years over year analysis result revealed that deficit irrigation levels significantly influenced maize grain yield at $p<0.05$. Result presented in Table 3 indicated that grain yield decreased with an increment of deficit application levels. The result indicated that there is no significant difference between mean grain yields obtained from 100%ETc and 75%ETc treatments but there is significant difference between mean grain yields obtained from 100%ETc and 50%ETc treatments. The maximum grain yield of 9318.6 kg/ha and 8550.2 kg/ha was obtained from 100%ETc and

75%ETc respectively and the lowest grain yield of 7905.2 kg/ha was obtained from 50%ETc treatment. There was 15.17 % significant yield reduction recorded through the application 50% deficit level as compared to full irrigation, while reducing the full irrigation application level by 25% produced 8.25 % non-significant yield reduction relative to the non-stressed treatment at $P<0.05$. Result obtained in this experiment in line with the findings of [17] who stated that maize grain yield reduced with decreasingin amount of irrigation water applied. According the same author, stressing the crop by 17 % and 33 % in relative to non-stressed treatment had no significant effect on grain yield, while applying 50 % and above deficit level causes a significant maize grain yield reduction.Results of different researcher indicate that it is possible to save up to 30 % irrigation water without sacrificing yield of maize through the adoption of deficit irrigation strategies [18, 19, 20].

The analysis of the resultsrevealed that means of irrigation water application in furrow irrigation significantly influenced maize grain yield at $p<0.05$. The result indicated that there is no significant difference between mean grain yields obtained from conventional furrow irrigation and alternate furrow irrigation treatments but there is significant difference between mean grain yields obtained from conventional furrow irrigation and fixed furrow irrigation treatments. Application of conventional furrow irrigation andalternate furrow irrigation gives a higher grain yield of 9284.6kg/ha and 8768.3kg/ha respectively and the lowest grain yield of 7721.1 kg/ha was obtained from 50%ETc treatment. Using alternate furrow irrigation method produced 5.5 % non-significant yield reduction relative to the conventional furrow irrigation at $P<0.05$, while fixed furrow irrigation had a significant grain yield reduction of 16.84 % as compared to conventional furrow irrigation. This result agreed with the findings of [12, 13] reported that there is 5.58 and 6.5 % non-significant yield reduction of maize through the application alternate furrow irrigation as compared to conventional furrow irrigation with saving of 50 % applied water. Also Kang *et al.* [10] evaluated the alternate furrow irrigation (AFI), fixed furrow irrigation (FFI) and conventional furrow irrigation (CFI) with different irrigation amounts for maize production. They reported that yield reduction in alternate furrow irrigation (AFI) was not significant with that of conventional furrow irrigation (CFI) unlikefixed furrow irrigation (FFI).

Remark: Water requirements (applied) for each treatment were indicated under Table 3.

Influence of Regular Deficit Irrigation and Alternate Furrow Irrigation on Dry Biomass of Maize: The two years over year analysis result on dry biomass of maize showed a significant difference on both deficit irrigation and furrow type treatmentsapplication. As indicated in Table 5 below above ground dry biomass decrease with increasing in deficit amount from 0 to 50 %. The analysis result showed that there is no significant difference between dry biomass obtained from 100%ETc and 75%ETc. Significant difference was observedin dry biomass between 100%ETc and 50%ETc. Plot receiving conventional furrow and alternative furrow irrigation gives maximum above ground dry biomass with a significant increment as compared to fixed furrow irrigation application. Generally reducing irrigation levels up to 25 % had no significant effect on above ground dry biomass while application of 50 % deficit level reduce the dry biomass of maize as compared to non- stressed treatment. Plant height and 100 seed weighthand no significant difference in case of both deficit level and furrow types (Table 5).

Influence of Regular Deficit and Alternate Furrow Irrigation on Water Productivity of Maize: Application of deficit level as well as furrow method had a significant effect on water productivity of maize. Table 6 describes, as the amount of water applied decreased water productivity of maize increased linearly from 2.15 kg/m^3 to 3.74 kg/m^3 in accordance with deficit level. Also alternate furrow and fixed furrow irrigation application gives the higher water productivity value with less water application as compared to conventional furrow irrigation.

Alternate furrow application had a significant water productivity increment as compared to both fixed furrow and conventional furrow irrigation by 12.18 % and 47.6 % respectively. This experimental result alsosupported by the findings of different researcher [10, 12] who stated that AFI maintained high grain yield with up to 50% reduction in irrigation amount, as a result, water use efficiency for alternate furrow irrigated field was substantially increasedand thistreatment was a better solution for water saving as compared to conventional furrow. According to the findings of Golzardi, Baghdadi and Afshar, [21] alternate furrow irrigation give higher water productivity than application of water at every furrow; also alternate furrow irrigation applied for potato increased irrigation water productivity by > 29% and contribute to maintain highly productive agricultural land under production with lower water supply [22].

Table 4: Effects of deficit levels and furrow types on grain yield

	Yield (kg ha^{-1})			
	Furrow type			
Water Requirement	AFI	FFI	CFI	Deficit Mean
100 % ETc	9270.8	8432	10253.1	9318.6^{a}
75 % ETc	9147.4	7307.7	9195.4	8550.2^{a}
50 % ETc	7886.8	7423.87	8405.3	7905.2^{b}
Furrow type Mean	8768.3^{a}	7721.1^{b}	9284.6^{a}	
LSD (5 %)	891.11			
CV (%)	10.4			

Table 5: Relative yield reduction over the control treatment

	Treatments	Mean grain yield (kg ha^{-1})	Relative grin yield reduction (kg ha^{-1})
Water Requirement	100 % ETc	9318.6	-
	75 % ETc	8550.2	8.25
	50 % ETc	7905.2	15.17
Furrow type	AFI	8768.3	5.56
	FFI	7721.1	16.84
	CFI	9284.6	-

Table 6: Effects of deficit levels and furrow types on dry biomass, plant height and 1000 seed weight

	Treatments	Dry Biomass (kg ha^{-1})	Plant Height (cm)	1000 seed weight (gm.)
Water Requirements	100 % ETc	26913^{a}	231.6	392.1
	75 % ETc	25227^{a}	229.2	385.1
	50 % ETc	22142^{b}	225.3	376.2
Furrow type	AFI	25597^{ab}	228.3	386.5
	FFI	21372^{b}	225.4	377.4
	CFI	27313^{a}	232.3	389.5
LSD(0.05)		2555	Ns	Ns
CV		10.32	3.37	8.69

Table 7: Maize Water productivity (kgm^{-3})

	Water Productivity (kgm^{-3})			
	Furrow type			
Water Requirements	AFI	FFI	CFI	Deficit Mean
100 % ETc	2.62	2.38	1.48	2.15^{c}
75 % ETc	3.25	2.75	1.9	2.58^{b}
50% ETc	4.7	4.16	2.75	3.74^{a}
Furrow type mean	3.53^{a}	3.1^{b}	1.85^{c}	
LSD (5 %)	0.3			
CV (%)	15.43			

CONCLUSION AND RECOMMENDATION

The results of this study showed that maize production in irrigated agriculture of the study area is recommended touse alternate furrow irrigation method with 75% irrigation water requirement level. Further study on deficit irrigation application at different growing stage for different promising maize variety is required at the study area.

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