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Research Article

The Effects of Every Other Furrow Irrigation Systems on Water Use Efficiency and Yield of Onion at Adami Tulu Agricultural Research Center

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Abstract

Alternate furrow irrigation was believed to improve water use efficiency and labor without a significant tradeoff in yield. It leads to see the effect of alternate furrow irrigation versus every furrow and fixed furrow were evaluated at full crop water requirement. With the objective of to evaluate effect of alternate furrow irrigation with two irrigation intervals (5day and 3day intervals) on crop yield water productivity that might enable to save irrigation water and labor. The experiment has been under taken among AFI, FFI and CFI at Adami Tulu Agricultural Research Center of experimental site for onion production. A field experiment was designed as a two factor factorial experiment (3*2) in RCBD, replicated three times. The two factors were irrigation systems and irrigation interval. Irrigation was applied to furrows using Parshal flume from furrows head ditch with similar inflow rate. Results obtained revealed that alternate furrow irrigation method produced total yield of 25203kg/ha which was not significantly different with that obtained under every furrow irrigation (26469kg/ha). Total yield harvested from fixed furrow irrigation were 24024kg/ha, which showed insignificant difference between the three methods. High marketable yield of 26053kg/ha was recorded from every furrow irrigation and the marketable yield of alternate furrow irrigation were 24601kg/ha which showed insignificant difference between the two method. Water productivity of 7.6kg/m3, 7.3kg/m^3 and 5.9kg/m^3 were produced under alternate furrow, fixed furrow and every furrow irrigation respectively. It was found that alternate furrow irrigation method saved 26.61% of water as compared to every furrow irrigation as well as fixed furrow irrigation method saved 26.81% as compared with every furrow irrigation method. Alternate furrow irrigation method with appropriate irrigation interval that is three days of irrigation interval is suitable irrigation method; for semi arid areas where soil is dominated by loam soil and water is liming factor for crop production.

Keywords

Alternate Irrigation, Irrigation Method, Irrigation Interval, Water Use Efficiency

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1. Introduction

Water plays a critical role in food production. It is estimated that 80% of the additional production required to meet the demands of the future will have to come from intensification and yield increase. Improved moisture control and irrigation are essential to achieve these. As reported by [7], the major agricultural use of water is used for irrigation, which is affected by decreased supply. Hence, innovations are needed to increase the efficiency of use of the water that is available. Better management of agricultural water for increased productivity and efficiency," More crop per drop", are of vital importance.

Agricultural water management will be the key to maintain food security and income generation for the rural poor. [11], also suggests that the key principle for improving water productivity at field, farm and basin level, which apply regardless of whether the crop is grown under rainfed or irrigated conditions are: (1) increase the marketable yield of the crops for each unit of water transpired by the plants; (2) reduce all out flows (e.g. drainage, seepage and percolation), including evaporative outflows other than the crop stomata transpiration; and (3) increase the effective use of rainfall, stored water, and water of marginal quality.

Inappropriate irrigation system design and management and the use of traditional irrigation methods have been reported to cause large water losses in agricultural fields [15]. Irrigation system upgrade and replacement can mitigate water shortages or lead to increased irrigated area to cope with rapid population growth [25].

Nowadays, there are different furrow irrigation systems developed to improve water application. One recent development towards optimum utilization of irrigation is to irrigate alternate furrows during each irrigation time [17]. Alternate furrow irrigation is an irrigation management strategy in which one out of two adjacent furrows is irrigated. By facilitating horizontal (lateral) water movement, alternate furrow has potential to reduce water losses via deep percolation and runoff. A number of researchers have reported that using alternate furrow irrigation reduces irrigation water use, often decreases crop yield, and results in an increase in water productivity [14, 18, 28]. These traits make alternate furrow irrigation convenient and economical in arid and semi-arid regions.

Alternate furrow irrigation (AFI) is considered to be one of the most effective tools to minimize water application and irrigation costs and produce a higher crop yield. It is a way to save irrigation water, improve irrigation efficiency, and thus a lower yield for a higher WUE [20]. AFI system is adopted where salt is a problem. This system save quite a good amount of water and is very useful and crucial in areas of water scarcity and salt problems [22]. It was concluded that alternate furrow irrigation is an effective water-saving irrigation method in arid areas where crop production relies heavily on repeated irrigation [17].

According to [19], application of alternate furrow irrigation system has improved irrigation water use. Under this furrow irrigation system, 56.7-72% of the water supply has been used to replenish soil moisture, 12-21.1% for infiltration within the temporary irrigation network and 11.3-17.8% for surface runoff. Working conditions of labors carrying out irrigation process were improved as this technology allowed them moving on the dry furrows.

It is necessary to develop efficient, reliable, and economically viable irrigation management strategies for effective use of the existing limited water resources. Improper irrigation management practices do not only waste scarce and expensive water resources but also decrease marketable yield and economic return. According to [10], the high seasonal and annual availability of water for agriculture, coupled with the requirement for higher agricultural productivity, means that the world has no option but to improve the water use efficiency. This has to include an efficient utilization of rainwater, which otherwise would be lost as evaporation or runoff. The productive use of water for agricultural production and rural development will need to improve continuously in order to meet targets for food production, economic growth, and the environment [5].

Therefore, the objective of this research study was to evaluate effect of alternate furrow irrigation with two irrigation intervals (5day and 3day intervals) on crop yield water productivity.

2. Materials and methods

2.1. Description of the Study Area

The experiment was conducted at the experimental site of Adami Tulu Agricultural Research Centre during off season for three consecutive years. The area is found at a latitude of 7° 9'N and 38° 7'E longitude at an altitude of about 1650 meters above sea level. The rainfall is bimodal and unevenly distributed with average annual rainfall of 760 mm. The minor and main rainfall periods are from February to April and July to September, respectively.

2.2. Materials Used

Materials used for the experiment were meteorological data, Cropwat software, Parshall Flume, soil augers, core samplers and double ring Infiltrometer. About 0.25 hectare of land for the experimental was prepared and tilled using animal drawn implements. Onion (*Allium cepa*), Bombay red variety was used as test crop.

2.3. Methodology

The seedlings were transplanted on well prepared experimental plots on both sides of furrow ridge at row and plant spacing of 20cm and 10cm, respectively. Single fertilization with DAP at transplanting and split application of urea at transplanting and 10 days after transplanting was done at a rate of 200kg/ha and 100kg/ha, respectively [24].

2.3.1. Crop Agronomy

CROPWAT model was used to determine water requirement of onion. Input data for the model were obtained from meteorological station at ATARC. Onion Bombe red having growing period of 125 days, was planted in the last week of October 2014/15 on nursery and transplanted to experimental plot on the third week of November 2014/15. All cultural practices other than treatment variables which are recommended for the area were used. Weed and insect controls were managed according to standard management practices. Onions were harvested by hand from the two center ridges of all plots.

2.3.2. Treatments and Experimental Design

The treatments considered for the experiment were two factors; namely, three irrigation systems and two irrigation intervals. The three irrigation systems are EFI (every/conventional furrow irrigation), AFI (alternate furrow irrigation), and FFI (fixed furrow irrigation) and the two irrigation intervals are three (3) and five (5) days. These irrigation intervals are adopted from previous onion crop water requirement determination study at ATARC (Adami Tulu Agricultural Research Center) at different growth stages. Based on this we proposed to use the minimum 3 days and maximum 5 days irrigation interval for this experiment at on-station. Thus, the treatment combinations are 1) Every/conventional irrigation method, irrigated at 3 and 5-days intervals; 2) Alternate furrow irrigation: only selective watering of every other furrow, that is, each bed receives water only on one side and alternating sides/furrow at 3 and 5-days intervals and odd furrows (1, 3, 5, etc.) were irrigated first followed by even furrows (2, 4, 6, etc.); and 3) Fixed furrow irrigation: means that, irrigation was fixed to one of the two neighboring furrows at 3 and 5-days intervals giving a total of 6 treatment combinations. The treatments were arranged in a randomized complete block design (RCBD) with three replications. Furrow was prepared on plot size of 5.0 m by 3.0 m and 0.1% slope along the advance that accommodates five furrows. There is 30 cm free space between plots and 1m wide road between replications.

The determined amount of irrigation water was applied using Parshall flume. Water productivity was determined by dividing grain yield by total applied irrigation water and is expressed as follows [2].

$$WP = GY/Wa, \quad (1)$$

Where GY is grain yield (kg ha^{-1}) and Wa is irrigation applied water (m^3 ha^{-1}).

2.3.3. Irrigation Water Management

Irrigation water was conveyed to the experimental plots through Parshall Flume of three inches. The amount of water for each experimental plot was added until reaching 95% of run length of the average of irrigated furrows. This is in accordance with local farmer practices in the area. Irrigation time was recorded with a stopwatch to estimate the amount of water applied to each plot. Furrows subjected to irrigation were open-ended; however, water does not exceed the edge of the plot because it flows through the parallel furrows, whereas other furrows not subjected to irrigation were closed-ended. The depth of applied water was calculated by using the following formula:

$$t = 10Ad/Q*60 \quad (2)$$

Where d is depth (cm); Q is discharge (L/s); t is time (min), and A is plot area (m^2).

The depth of applied water varied according to the time for each irrigation treatment. Total depth of applied water (Wa) was the sum of the amounts of water added at each irrigation event during the entire growing season.

2.3.4. Irrigation Water Requirement of Onion

The water requirement of onion was computed for the growing season of 95 days using the CROPWAT computer program with climate, soil and crop input data from the experimental area. The onion crop coefficient, root depth, length and growing stages used as inputs for CROPWAT program computation were taken from [3]. The net irrigation requirement was calculated using the CROPWAT computer program based on [3]. The gross irrigation requirement of the onion was calculated with the assumed application efficiencies of 60%.

2.3.5. Data Collected

During the experiment was conducted important data for the experiment like daily meteorological data, in-situ and laboratory analysis data on soil physical and chemical properties and data on crop development relevant to assess the response of the crop to irrigation treatments were collected.

Climate data

Long term climatic data and daily records of climatic factors such as rainfall, maximum and minimum temperature records, wind speed, relative humidity, and sunshine duration for 20 years (2000-2019) were collected for the experimental period from meteorological station at ATARC.

Soil analysis

The soil was characterized in terms of its physical and chemical properties. The soil properties analyzed include, texture, organic carbon, bulk density, water retention at FC and PWP and pH. The samples were taken from three points along the diagonal of the experimental plot and from two depths (0-20cm and 20-40cm). Soil texture was determined using pipette method. Organic carbon content was determined by titration method using chromic acid (potassium dichromate + H2SO4) digestion according to [26] method.

Moisture contents at field capacity and permanent wilting point were measured using a pressure plate apparatus at National Soil Laboratory by applying pressures at 0.33 and 15 bars, respectively. The moisture content of the soil samples on volume basis were determined by multiplying the gravimetric water content on weight basis by the bulk density. pH was measured in 1:1 soil: water mixture by using a pH meter. Distilled water was used as a liquid in the mixture. Ten gram air dried < 2 mm soil was weighed into 100 ml beakers and 10 ml distilled water was added to 1:1 soil/water suspension and transferred to an automatic stirrer, to be stirred for 30 minutes and pH on the upper part of the suspension was measured.

The soil bulk density is defined as the oven dry weight of soil in a given volume, as it occurs in the field. It was determined by core method. Soil bulk-density data was taken as cores of 100cm^3 volumes in the field at two depths 0-20cm, and 20-40cm oven dried for 24 hrs at 105 ℃ and weighed for dry density using the following formula.

$$\rho b = \frac{Wd}{Vc} \quad (3)$$

Where ρ_b= soil bulk-density (g/cm^3)

Wd = weight of dry soil (g)

Vc = volume of core (cm^3)

Double ring infiltrometer was used to measure basic infiltration rate of the soil. The test was done at location in the experimental plot, randomly selected.

Yield collection

Since individual treatment had five furrows, yield was collected from the central two furrow of each treatment. During yield collection, each treatment furrow divided into four parts along the furrow length. In order to see the yield difference along the furrow, onion yields were collected from the four quarters and weighed separately whereas for the analysis purpose it was summed. The harvested yield graded into marketable and non-marketable categories according to the size and degree of damage. Onion bulbs with less than 2 cm diameter were categorized under non-marketable [21].

Water use efficiency

The water use efficiency was calculated by dividing harvested yield in kg per unit volume of water (kg/m^3). Two kinds of water use efficiencies, namely total water use efficiency (CWUE) and net irrigation water use efficiency (FWUE) were calculated.

Crop water use efficiency: The crop water use efficiency is the yield harvested per ha-mm of total water used.

$$CWUE = \frac{Y}{ET_c} \quad (4)$$

Where: CWUE = crop water use efficiency (kg/ha-mm)

Y = grain yield in kg ha-1 and

ET = is evapotranspiration (mm)

Field water use efficiency: Field water use efficiency is the yield harvested per ha-mm of net depth infiltrated.

$$FWUE = \frac{Y}{I_I} \quad (5)$$

Where: FWUE = field water use efficiency (kg/ha-mm)

Y= grain yield in (kg/ha)

I_g= gross irrigation is in (mm)

Benefit-Cost Ratio (BCR) and Net Return (NR*)*

The total cost mainly includes labor, input, chemical and fuel costs. Labor cost included costs for land preparation, weeding and watering and estimated based on the study area. Input costs included costs for purchasing of seed and fertilizer. The farmers in the study area do not pay for water for their farms. Therefore, they only bear the costs of labor for land preparation, weeding and watering (estimated the man-day labor cost of 100 Ethiopian Birr) as well as the price of seed, fertilizer and fuel to run a pump to withdraw water from the channel. Therefore, labor cost, input cost, chemical and fuel costs of the three irrigation method were estimated at plot level based on the observed costs and converted to hectare.

In the study area majority of the farmers are using pumps to convey water from the river channels to their farm land. Based on this fact fuel cost was estimated at plot level and converted to hectare. Gross revenue had been calculated by multiplying marketable yield in kg ha^{-1} and onion market price per kilogram. The farm-gate price for onion in this study was 10 Ethiopian Birr per kilogram (local price). Net return (NR) and benefit-cost ratio (BCR) due to irrigation were calculated as follows:

$$NR = GR - TC \quad (6)$$

$$BCR = NR/\text{Total costs} \quad (7)$$

Where: NR Net return (ETB), GR Gross revenue (ETB), TC Total costs (ETB) and BCR Benefit-Cost ratio.

2.3.6. Data Managements and Analysis

The data was handled and documented appropriately. Frequent monitoring and evaluation technique was employed to control reliability of the data. The data collected during the field studies were compared using statistical analysis, ANOVA. When the treatment effects are found significant, LSD test was used to see the significant difference among the mean values of the treatments.

3. Result and Discussions

3.1. Soil Characterization

The results of textural analysis using Hydrometer method of the soil from the experimental site showed that the composition of sand, silt and clay percentage were 30.26, 47.03 and 20.13%, respectively. Thus as per the USDA texture triangle classification, the soil was classified as loam soil. The volumetric soil moisture content at the field capacity and permanent wilting point of the soil were determined to be 36.65 and 20.96 percent, respectively. The infiltration rate determined from ring infltrometer data was 34.0 mm/hr. The above information showed that the soil was categorized under loam soil with good water holding capacity (i.e., total available water of 156.95 mm/m) with low infiltration rate. The laboratory results of the soil physical and chemical characteristics for (0-20 cm) and (20-40 cm) are as indicated in Table 1.

Table 1. *The physical and chemical characteristics of the soil at ATARC.*

Soil property		Soil depth (cm)		
		(0-20)	(20-40)	Average
Particle size distribution	Sand (%)	31.05	29.47	30.26
	Silt (%)	47.19	46.86	47.03
	Clay (%)	18.56	21.70	20.13
Textural class		Loam	Loam	Loam
Bulk density (g/cm^3)		1.02	1.06	1.04
pH		7.15	7.17	7.16
EC (ds/m)		1.3	1.5	1.4
FC (Vol %)		38.08	35.22	36.65
PWP (Vol %)		19.91	22.00	20.96
TAW (mm/m)		181.70	132.20	156.95

3.2. Rain Fall Distribution of Study Area

The average Twenty years rainfall data was collected from Adami Tulu Metrological Station. The effective rain fall was computed by the CROPWAT program for the monthly total rainfalls. The average total rain falls were 755.9mm and the total effective rain were 383.5.

Table 2. *The average total rain fall of the study area.*

Months	Total rain fall	Effective rain
January	9.4	0.0
February	18.3	1.0
March	57.3	24.4
April	69.6	31.8
May	86.1	44.9
June	84.3	43.4
July	164.2	107.4
August	119.6	71.7
September	78.9	39.1
October	49.8	19.9
November	11.9	0.0
December	6.5	0.0
Total	755.9	383.5

3.3. Reference Evapotranspiration (ETo)

The reference evapotranspiration of the study area was computed and the result is presented in table below. The average reference evapotranspiration (ET_o) of the site was found to be 4.57 mm/day.

Table 3. *The reference evapotranspiration of the study area.*

Months	Max. temp (℃)	Min. temp (℃)	RH (%)	WS (km/day)	Sunshine hour (hrs)	ET_O (mm/day)
January	28.6	10.2	52	143	8.9	4.53
February	30.1	11.1	47	146	9.3	5.11
March	30.5	12.8	51	136	8.6	5.13
April	30.0	14.1	54	139	8.2	5.04
May	29.4	15.2	59	149	8.0	4.83
June	28.2	15.1	62	197	7.5	4.74
July	25.3	14.8	70	185	5.8	3.90
August	25.4	14.6	71	147	6.3	3.92
September	26.6	13.7	68	117	6.6	4.04

Months	Max. temp (℃)	Min. temp (℃)	RH (%)	WS (km/day)	Sunshine hour (hrs)	ET_O (mm/day)
October	28.0	11.4	57	113	8.0	4.39
November	28.3	10.1	52	147	9.3	4.69
December	27.7	9.1	50	143	9.4	4.47
Mean	28.2	12.7	57.8	146.8	8.0	4.6

3.4. Crop Water Requirement of Onion

The crop water requirement of the test crop calculated by multiplying the referance ETo with crop coefficient (Kc). The onion crop water requirement and irrigation water requirement is presented in table below.

Table 4. Crop water requirement and irrigation water requirement of onion.

Date	Crop Kc	CWR (ETm) (mm/day)	CWR (ETm) (mm/period)	Effe rain (mm/period)	Irrigation requirement (mm/period)
20/11/20	0.7	3.28	19.7	0.0	19.7
30/11/120	0.7	3.23	32.3	0.0	32.3
10/12/20	0.72	3.29	32.9	0.0	32.9
20/12/20	0.83	3.73	37.3	0.0	37.3
31/12/20	0.96	4.30	47.3	0.0	47.3
10/01/20	1.05	4.72	47.2	0.0	47.2
20/01/21	1.05	4.75	47.5	0.0	47.5
31/01/21	1.05	4.96	54.5	0.1	54.5
10/02/21	1.03	5.04	50.4	0.0	50.4
18/02/21	0.97	4.95	34.7	0.0	34.7
Total			403.9	0.1	403.9

3.5. Applied Irrigation Water

The amounts of applied water for each treatment throughout the growing season of the crop were summarized in the table below.

Table 5. The amounts of applied water in mm/season for each treatment.

Year	Treatments					
	AFI3	AFI5	EFI3	EFI5	FFI3	FFI5
2020	389	265	471	429	381	278
2021	395	272	475	435	385	270
2022	387	278	461	433	379	285
Mean	390.3	271.7	469	432.3	381.7	277.7

Each treatment with the same irrigation interval has the same number of irrigation events. The seasonal amount of Wa (applied irrigation water) for each treatment is the sum of Wa applied at each irrigation events. The overall mean study indicates that fixed furrow irrigation treatments saved more water than both alternate and every furrow irrigation system. The mean high amount of seasonal water applied (469 mm/seasonal) was recorded under every furrow irrigation at three day intervals (EFI3), while the low (271.7 mm/seasonal) was recorded under alternate furrow irrigation at five day intervals (AFI5). When we compared seasonal water applied for similar irrigation interval for each treatment, high amount (469mm/season) of water was applied for EFI3 while low amount (381.7 mm/season) was applied for FFI3. Similarly high amount (432.3) of seasonal water was applied under EFI than both AFI (271.7) and FFI (277.7) at five days of irrigation interval. This might be due to the great reduction of wetted surface in AFI and FFI than EFI at both irrigation intervals. Almost half of the soil surface is wetted in AFI and FFI as compared with EFI. This result supports the outcome obtained by [13], who found that AFI methods can supply water in a way that greatly reduce the amount of wetted surface, which leads to less evapotranspiration and less deep percolation. The amount of Wa with AFI at 3 days interval was greater than at 5 days interval. This can be attributed to more frequent irrigation under the AFI3 treatment by [1]. Reduced irrigation water due to the AFI system was reported by [8] for onion; [27] for wheat; [16] for sugar beet; [23].

3.6. Effects of Furrow Irrigation Systems on Yield and Yield Components of Onion

3.6.1. Effect on Bulb Size and Bulb Diameter

Irrigation Interval: The irrigation interval were significantly different from each other in Bulb size and bulb diameter at ($P < 0.05$). Significantly higher, bulb diameter (5.05 cm) and bulb size (4.21 cm) were recorded by three days of irrigation interval respectively. On the other hand the lowest size of bulb of 4.01 cm and 4.76cm of bulb diameter were observed in five days of irrigation interval, respectively.

Table 6. Effect of irrigation method and irrigation interval on stand count, bulb size and bulb diameter.

Treatments		Bulb size (cm)	Bulb diameter (cm)
Irrigation Method	AFI	4.18a	4.86ab
	EFI	4.22a	5.03a
	FFI	3.92b	4.83b
	LSD 0.05	0.21	0.19
Irrigation Interval	Days		
	3	4.21a	5.05a
	5	4.01b	4.76b
	LSD 0.05	0.17	0.15

Irrigation Method: Fixed Furrow Irrigation was found different from others; it is significantly different on bulb size. Significantly higher bulb size (4.22cm) and (4.18cm) were recorded under EFI and AFI systems respectively. Significantly lower bulb size (3.92cm) was recorded on FFI method.

Significantly higher bulb diameter (5.03cm) was recorded at EFI and significantly lower (4.83cm) was observed at FFI. There is no significant difference on bulb diameter between AFI and EFI, and also between FFI and AFI.

Table 7. Combination effects of furrow systems on bulb size and bulb diameter.

Furrow system	Irrigation Interval	Bulb size (cm)	Bulb diameter (cm)
AFI	3	4.29a	4.99ab
	5	4.08ab	4.73bc
EFI	3	4.31a	5.19a
	5	4.13a	4.87bc
FFI	3	4.02ab	4.97ab
	5	3.81b	4.68c
	LSD 0.05	0.29	0.27
	CV	7.56	5.73

The combination effect showed significant difference on bulb size. Significantly higher bulb size of (4.31cm) was recorded in combination treatment of Every Furrow Irrigation with irrigation scheduling of three days interval. Similarly onion bulb size of 4.29cm and 4.13cm were recorded in treatment combination of AFI3 and EFI5 respectively. But the combination effect of FFI with five days irrigation interval of applied water were highly significantly different with that of AFI3, EFI3 and EFI5 respectively. However, there is no significant different between the combination treatment of when AFI with three and five days interval, EFI with three and five days interval, and FFI with three days of interval of water were applied.

On the other hand the combination effect of irrigation method with irrigation interval showed that there was significant difference on bulb diameter. There were highly significant difference in combination effects of treatments between FFI with five days interval (FFI5) and EFI with three days interval (EFI3), AFI with three days interval and FFI with three days interval respectively. But there is no significant in combination between treatments of EFI3, AFI3 and FFI3. Similarly no significance deference observed between AFI3, AFI5, EFI5 and FFI3, and also b/n treatments of AFI5, EFI5 and FFI5. Significantly higher bulb diameter of 5.19cm was recorded on treatment combination of EFI with three days irrigation interval (AFI3) of irrigation water applied. AFI3 of 0.46cm, 0.32cm, 0.51cm greater than the treatment combination of AFI with three days interval, EFI with five days interval and FFI with five days interval of irrigation scheduled respectively.

3.6.2. Effect on Bulb Weight, Under and Over Sized Bulb

Irrigation Method: The irrigation methods were no significantly different from each other in bulb weight at (P 0.05). Significantly higher bulb weight of 84.67 gm was recorded by Every Furrow Irrigation (EFI) system of water applied while Alternate Furrow Irrigation (AFI) method of water applied recorded the lowest bulb weight of 76.44 gm. The effects of irrigation method on under size and over size were significantly different. Significantly higher 5.64, 3.91 Quintal per hectare of under size were recorded on Alternate Furrow Irrigation (AFI) and Fixed Furrow Irrigation (FFI) respectively. Significantly lower 1.47 Quintal per hectare at Every Furrow Irrigation (EFI). Among the three furrow irrigation system, Alternate Furrow Irrigation was found that over size of 4.17, 1.73 Qt/ha greater than EFI and FFI respectively. On the other hand significantly higher over size of 9.32 Qt/ha were recorded on FFI while significantly lower 0.78 Qt/ ha were observed on AFI. There is no significant difference between FFI and AFI, EFI on under size respectively. Similarly there is no significance difference on over size between AFI and EFI.

Table 8. *The effect of irrigation method and irrigation interval on bulb weight, under and over sized bulb in three years.*

Treatment		Bulb weight (gm)	Under size (Qt/ha)	Over size (Qt/ha)
Irrigation Method	AFI	76.44a	5.64a	0.78b
	EFI	84.67a	1.47b	3.19b
	FFI	76.64a	3.91ab	9.32a
	LSD 0.05	8.29	2.66	5.01
Irrigation Interval	Days			
	3	84.41a	3.17a	7.21a
	5	74.09b	4.18a	1.65b
	LSD 0.05	6.77	2.17	4.09

Irrigation Interval: Irrigation interval, in its main effect, on bulb weight and over size were significantly different at ($P < 0.05$). Significantly higher of bulb weight (84.41 gm) and 7.21Qt/ha oversized bulb were observed at three days of irrigation interval. Whereas significantly lower (74.09 gm) and (1.65 Qt/ha) were recorded on irrigation interval of five days of irrigation interval. Irrigation interval has no effect on under sized bulb. Higher under size of 4.18 Qt/ha were recorded in five days irrigation interval while lower 3.17 Qt/ha were observed in three days of irrigation interval. Values of bulb weight were decreased by 13.93% at five (5) when irrigation water was applied at five days interval.

Table 9. *Combination effects on bulb weight, under and oversized bulb.*

Furrow system	Irrigation Interval	Bulb weight (gm)	Under sized (Qt/ha)	Oversized (Qt/ha)
AFI	3	81.33ab	6.17a	0.83b
	5	71.56b	5.12ab	0.72b

Furrow system	Irrigation Interval	Bulb weight (gm)	Under sized (Qt/ha)	Oversized (Qt/ha)
EFI	3	91.78a	1.10c	6.39b
	5	77.56b	1.84bc	0.00b
FFI	3	80.11ab	2.24bc	14.41a
	5	73.17b	5.58ab	4.23b
	LSD 0.05	11.72	3.76	7.08
	CV	15.56	10.70	16.81

Irrigation furrow methods showed significant effect in combination with irrigation interval on bulb weight and over sized bulb at (P < 0.05) (Table 9). Every Furrow Irrigation system produced 77.56gm bulb weight with five days irrigation interval, which increased to 91.78 gm bulb weight with three days irrigation interval. Values of average single bulb weight in grams were increased by 18.33%, 13.65% and 9.48% at three (3) day irrigation interval when compared with five days irrigation interval for EFI, AFI and FFI respectively. As for the combination effect on the under size, data show that the more under size of 6.17 Qt/ha were recorded in treatment combination of AFI with three days of irrigation interval followed by 5.58 Qt/ha, 5.12 Qt/ha on FFI and AFI with five days intervals respectively. The lowest undersized bulb value of 1.1 Qt/ha was observed when EFI interact with three days of irrigation interval. As the data shows in (table) significantly higher over sized bulb (14.41Qt/ha) was recorded on FFI with three days irrigation interval.

3.6.3. Effect on Marketable Yield

Table 10 shows that there was significant difference (P<0.05) between the marketable yields obtained under EFI and FFI treatments. Nevertheless, there was no significant difference between EFI and AFI treatments. But there was a significant reduction in the volume of water applied to the AFI treatments. The reason probably is due to better application efficiency obtained with AFI system. This is consistent with the significant loss of water that has been associated with CFI by [13], physiological response associated with AFI [12, 17, 30] and less evapotranspiration associated with AFI [29].

Significantly higher marketable yield of 260.53 Qt/ha was recorded by EFI system followed by AFI (246.01Qt/ha) and FFI (228.18Qt/ha) respectively. There is no significant different between EFI and AFI. There was observed no significance difference considering total yield, but EFI gave yield advantage of 4.78% and 9.24% for AFI and FFI respectively. On the other hand, significantly higher marketable yield was recorded at irrigation interval of three days and its yield advantage is 16.14% than that of five days irrigation interval.

As shown in Table 11, the combined effect of irrigation method with irrigation interval showed significance difference on marketable yield at (P<0.05). Significantly higher 296.62 Qt/ha marketable yield was recorded on AFI with three days of irrigation interval with yield advantage of 12.16% and 18.41% as compared to EFI and FFI respectively. A treatment combination of AFI with three days interval significantly differed from treatment combination of AFI with five days irrigation interval, FFI with three and Five days of irrigation interval, But there is no significant difference with treatment combination of EFI with three and five days of irrigation interval. Even if they have no significant different AFI3 gave 12.16% and 12.18% more marketable yield than EFI3 and EFI5. This may be attributed to the better availability of soil moisture during the irrigation cycle under (AFI). The same trend of water saving advantage showed in AFI3 of 16.78% and 9.72% amount of water saved than applied water of EFI3 and EFI5 respectively.

It was shown that the soil moisture contents between the two neighboring furrows in AFI remained different until the next irrigation, with higher water content in the previously irrigated furrow. This pattern of soil moisture distribution in the crop root zone should allow part of the root system to be always exposed to a drying soil, consequently, the uniformity of soil moisture distribution in the AFI treatments didn't change noticeably when irrigation amounts was reduced [20].

Table 10. *Effect of irrigation method and irrigation interval on marketable yield and total yield.*

Treatment		Marketable yield	Total yield
Irrigation Method	AFI	246.01ab	252.03a
	EFI	260.53a	264.69a
	FFI	228.18b	240.24a
	LSD 0.05	30.41	30.84
Irrigation Interval	Days		
	3	266.40a	275.78a
	5	223.41b	228.87b
	LSD 0.05	24.83	25.18

Total Yield

An irrigation method does not show significance difference over total yield at (P >0.05). The maximum total yield observed was 264.69 Qt ha^{-1} (EFI) which is not significantly different from AFI (252.03 Qt ha^{-1}). The lower 240.24 Qt ha^{-1} total yield was recorded on FFI of irrigation furrow method.

But it was observed significant difference of irrigation interval on total yield at (P<0.05). Significantly higher (275.78 Qt ha^{-1}) total yield was recorded on three days irrigation interval than at five days irrigation interval. The combination effect of irrigation method with irrigation interval had a significant effect on total yield at (P<0.05). Significantly higher yield were recorded on treatment combination of AFI with three days irrigation interval which was not significantly different from Every Furrow irrigation with three and five days interval. A higher total yield (303.62 Qt/ha) was recorded on AFI with three days of irrigation interval whereas lower total yield (200.44 Qt/ha) was observed in AFI with five days irrigation interval.

The treatment combination of AFI with three days irrigation interval had shown a better total yield (12.05% and 13.6% yield advantage) as compared to EFI with three and five days of irrigation interval respectively. Similarly, AFI with three days interval gave 33.98%, 15.46% and 26.28% more total yield than AFI with five days irrigation interval, FFI with three and five days of irrigation interval respectively.

Table 11. *Combination effect on marketable yield and total yield.*

Furrow system	Irrigation Interval	MaYld (Qt/ha)	ToYld (Qt/ha)
AFI	3	296.62a	303.62a
	5	195.39d	200.44c
EFI	3	260.56ab	267.04ab
	5	260.50ab	262.34ab
FFI	3	242.02bc	256.67b
	5	214.34cd	223.82bc
	LSD 0.05	43.01	43.61
	CV	18.48	18.19

3.6.4. Effect on Water Use Efficiency

From Table 12 there is significant difference (P<0.05) between the results of CWUE of irrigation furrow method and irrigation interval and also one can clearly see that, the three furrow irrigation systems were better performance at reduced water application level. In addition, AFI was better than EFI and FFI at all reduced amount application level.

Table 12. *Effect irrigation method and interval on crop water use efficiency and irrigation water use efficiency.*

Furrow system	ToYld (Qt/ha)	CWR (mm)	Applied water (mm)	CWUE	IWUE
AFI	252.03	197.05	331	1.28a	0.76a
EFI	264.69	394.1	451	0.67b	0.59b
FFI	240.24	197.05	330	1.22a	0.73a
Irrigation interval					
3	275.78	394.1	414	0.70a	0.67b
5	228.87	394.1	327	0.58b	0.70a

This finding agreed with result states that an adverse relationship was found between the amounts of water applied and water productivity of the crop by [16]. The applied water was used more efficiently in the alternate furrow irrigation treatment in which the lower amount of water applied produces higher water productivity value.

Table 12 also shows that the difference observed in water productivity between alternate and fixed furrow irrigations was not statistically significant at 5% significant level. The same amount of irrigation water was applied for alternate furrow and fixed furrow irrigation techniques. However, alternative drying of root zone under alternate furrow irrigation method showed higher water productivity than fixed drying of root zone under fixed furrow irrigation method. This is due to uniform water distribution between ridges in alternate furrow than fixed furrow irrigation. Uniform water distribution between ridges in alternate furrow irrigation method enhanced root growth and improved nutrient uptake of crop which increases the yield than fixed furrow irrigation method.

The highest WUE was registered in FFI with three days of irrigation treatment, the onion crop using better the water applied in small quantities and often. The highest WUE value under limited water supply, i.e. 8.1 kg/m^3 and 7.8 kg/m^3, was observed when FFI and AFI irrigation method with five and three days interval were used. These results are in accordance with [1, 4, 9] who concluded that (AFI) improved crop water utilization efficiency for the crop under study.

Table 13. C0ombination effect on crop water use efficiency and irrigation water use efficiency.

Furrow system	Irrigation Interval	Total yield (Qt/ha)	CWR (mm)	Applied water (mm)	CWUE (kg/m³)	IWUE (kg/m³)
AFI	3	303.62	197.05	390.3	15.4a	7.8a
	5	200.44	197.05	271.7	10.2b	7.4ab
EFI	3	267.04	394.1	469	6.8c	5.7d
	5	262.34	394.1	432.3	6.7c	6.1cd
FFI	3	256.67	197.05	381.7	13.0ab	6.7bc
	5	223.82	197.05	277.7	11.4b	8.1a

The results of statistical analysis indicate that the alternate furrow irrigation system resulted in highest CWUE compared to the fixed furrow irrigation system i.e. there was significant difference ($P<0.05$) between the CWUE obtained in between AFI and EFI and also b/n FFI and EFI. The total water used by AFI and FFI system reduced to some extent that contributes to increment of total water use efficiency. This is consistent with the significant improvements in CWUE that have been associated with AFI [30].

3.7. Irrigation Water Saved and Additional Area of Irrigated

Table 14 indicated that amount of water saved under each irrigation methods comparing with each other. This table also indicated that additional area can be irrigated by amount of water saved under each irrigation methods. AFI3 and AFI5, FFI3 and FFI5 and EFI5 saved 78.7mm and 197.3mm, 87.3mm and 191.3mm and 36.7mm more water than of water applied under EFI3 respectively, the amount of water saved in comparison can be utilized to irrigate another additional land of the same crop additionally. On which the amount of water gained/profited leads to irrigate extra 0.2ha and 0.73ha, 0.23ha and 0.69ha and 0.08ha of additional land using the irrigation system of AFI3 and AFI5, FFI3 and FFI5 and EFI5 when compared to EFI3 for onion production respectively (table 14). Similarly AFI3 and AFI5, FFI3 and FFI5 saved 42mm and 160.6mm, 50.6mm and 154.6mm of water applied under EFI5 which can be used to irrigate extra 0.11ha and 0.59ha, 0.13ha and 0.56ha of additional land using the irrigation system of AFI3 and AFI5, FFI3 and FFI5 when compared to EFI5 for onion production respectively. AFI5, FFI3 and FFI5 saved more water 118.6mm, 8.6mm and 112.6mm than of water applied under AFI3 which can be used to irrigate extra 0.44ha, 0.02ha and 0.41ha of additional land using the irrigation system of AFI5, FFI3 and FFI5 when compared to AFI3 for onion production respectively.

Table 14. Irrigation water saved and additional area gained under each treatments.

Treatment: Furrow system	Irrigation Interval	Irrigation water used (mm)	Irrigation water saved (mm) Comparing with EFI3	Extra land that can be irrigated (ha)	Irrigation water saved (mm) Comparing EFI5	Extra land that can be irrigated (ha)	Irrigation water saved (mm) Comparing with AFI 3	Extra land that can be irrigated (ha)	Irrigation water saved (mm) Comparing with FFI 3	Extra land that can be irrigated (ha)	Irrigation water saved (mm) Comparing with FFI 5	Extra land that can be irrigated (ha)
AFI	3	390.3	78.7	0.20	42	0.11	0	0	-	-	-	-
	5	271.7	197.3	0.73	160.6	0.59	118.6	0.44	110	0.40	6	0.02
EFI	3	469	0	0	-	-	-	-	-	-	-	-
	5	432.3	36.7	0.08	0	0	-	-	-	-	-	-
FFI	3	381.7	87.3	0.23	50.6	0.13	8.6	0.02	0	0	-	-
	5	277.7	191.3	0.69	154.6	0.56	112.6	0.41	104	0.37	0	0

In the same manner AFI5 and FFI5 saved more water of 110mm and 104mm than the amount of water applied under FFI3 which can be used to irrigate extra 0.4ha and 0.37ha of additional land using the irrigation system of AFI5 and FFI5 when compared to FFI3 for onion production respectively.

3.8. Benefit-Cost Ratio (BCR) and Net Return (NR)

Table 15. Expenses involved in the implementation of irrigation treatments.

Treatments		Labor cost (ETB)		Input cost (ETB)		Chemical cost (ETB)	Fuel cost (ETB)	Total cost (ETB)
Furrow system	Irrigation Interval	Land preparation &Weeding	Watering	Fertilizer	Seed			
AFI	3	25000	9000	6400	10000	25000	5500	80900
	5	19000	6000	6400	10000	25000	2750	69150
EFI	3	33000	24000	6400	10000	25000	11000	109400
	5	27000	12000	6400	10000	25000	5500	85900
FFI	3	25000	9000	6400	10000	25000	5500	80900
	5	19000	6000	6400	10000	25000	2750	69150

Table 16. Revenues gained from the implementation of irrigation treatments.

Treatments		Marketable yield $kgha^{-1}$	Unit price (Per Kg)	Total price
Furrow system	Irrigation Interval			
AFI	3	29662	10	296620
	5	19539	10	195390
EFI	3	26056	10	260560
	5	26050	10	260500
FFI	3	24202	10	242020
	5	21434	10	214340

Estimation of cost and revenue earned was done based on the expenses involved to produce onion around study area and revenues can be gained from production onion in the study area. Estimated benefit-cost ratio (BCR) and net return (NR) were affected by the irrigation techniques. Maximum benefit-cost ratio (BCR) was 2.67 obtained from alternate furrow irrigation with three days of irrigation interval followed by 2.1 from fixed furrow irrigation with five days of irrigation interval and 2.03 from every furrow irrigation technique with five days of irrigation interval, whereas minimum benefit-cost ratio of 1.38 was observed from every furrow irrigation technique with five days of irrigation interval.

However, net revenue gained from alternate furrow irrigation with five days interval was low as a result of low marketable yield collected from this treatment as compared with others. From the results of this study, alternate furrow irrigation with three days of irrigation interval was the best method to improve water productivity, water use efficiency and economic return from onion production. The result of benefit-cost ratio indicated in Table 17 showed that all irrigation methods are feasible. However by comparing alternate furrow irrigation with other methods, farmers can get more benefit from alternate furrow irrigation using with three days of irrigation interval compared to other irrigation methods.

Table 17. Benefit-cost ratio (BCR) and net return (NR) associated with the adopted irrigation treatments.

Treatments		Applied water m^3ha^{-1}	Labor cost ETB ha^{-1}	In put cost ETB ha^{-1}	Chemi-cal cost ETB	Fuel cost ETB	Total cost ETB	Marketable yield $kgha^{-1}$	Gross Revenue ETB	Net reve-nue ETB	Bene-fit-cost ratio
Furrow system	Irrigation Interval										
AFI	3	3903	34000	16400	25000	5500	80900	29662	296620	215720	2.67
	5	2717	25000	16400	25000	2750	69150	19539	195390	126240	1.83
EFI	3	4690	57000	16400	25000	11000	109400	26056	260560	151160	1.38
	5	4323	39000	16400	25000	5500	85900	26050	260500	174600	2.03
FFI	3	3817	34000	16400	25000	5500	80900	24202	242020	161120	1.99
	5	2777	25000	16400	25000	2750	69150	21434	214340	145190	2.10

4. Summary and Conclusion

In this study, an attempt was made to evaluate the effect of Alternate, Every and Fixed furrow irrigation systems and two irrigation intervals three and five days water application and to emphasized on comparison of irrigation methods to identify the irrigation management strategies which could contribute for water saving, increase water productivity and water use efficiency with no or minimum yield reduction in the mid rift valley particularly east Shoa zone of Oromia region in Adami Tulu Agricultural Research Center for onion production.

Alternate furrow irrigation system, was considered as improved irrigation technology and its performance was evaluated in comparison with FFI and EFI. From the study the highest total yield was observed under every furrow irrigation method which showed little difference as compared with alternate furrow irrigation. The yield reduction observed under alternate furrow irrigation is less than 5% as compared with every furrow irrigation method, which has no significant impact on total yield of onion crop. The highest marketable yield (26053kg ha^{-1}) was obtained from every furrow irrigation, whereas the lowest marketable yield (22818 $kgha^{-1}$) was obtained from fixed furrow irrigation.

Comparing the results of the irrigation methods from the point of crop water productivity, it clearly confirmed that, alternate furrow irrigation method had more beneficial use of water followed by fixed furrow irrigation and every furrow irrigation methods respectively. The highest water productivity (WP) value (7.6kg m^{-3}) was obtained under alternate furrow irrigation whereas the lowest value (5.9kg m^{-3}) was obtained under every furrow irrigation.

Alternate furrow and fixed furrow irrigation methods saved 26.61% and 26.83% of water applied as compared to every furrow irrigation method respectively.

Results obtained from this study show that the AFI system lead to lesser water input yet was still able to generate onion yield comparable to EFI. AFI keep yield same to EFI, these results were obtained while it maintains acceptable onion yield and quality. AFI and FFI were also saved labor by 50% because in EFI four furrows irrigated at same time while in AFI and FFI only two furrows out of four furrows. Therefore, time and labor reduced by half and improves working conditions as technology allows irrigator moving on the dry furrows.

The study results confirmed that with alternate irrigation strategy it is possible to increase water productivity 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 26.61% of water applied compared to every furrow irrigation method which is sufficient to irrigate other cropped land.

Therefore applying alternate-furrow irrigation with appropriate irrigation intervals is efficient method in the study area and water become limiting factor for crop production. It can be conclude that using alternate irrigation is a good water management technique to save irrigation water without reducing the yield of onion crop. The preference between alternate furrow irrigation method and other methods depends on the value of water in relation to crop returns. This water application technique is much important for semi arid areas of Ethiopia where limited amount of water is available for irrigation and irrigation water management is very poor.

In conclusion, AFI is a practicable method, and should be of significant value to arid areas because many of these areas face diminishing water resources. A sustainable use of water resources is increasingly becoming an urgent world-wide problem. Moreover, the difference in yield is sufficient to do the extra work involved in changing the water management to alternate irrigation. AFI can save a substantial amount of water and labor without reduction of onion yield. This also demonstrates that crop water use efficiency will be increased by using AFI which may result in substantial benefits, under limited water condition, labor saving and improved flexibility in farm irrigation management are also expected to be achieved using AFI. This result should be of significant value in this area to irrigate additional land.

5. Recommendations

Generally this study would like to recommend farmers, water managers, and water use associations to use water efficiently using alternate furrow irrigation and increase their agricultural production by expand irrigable land with existing amount of water in a given irrigation scheme. Therefore, alternate furrow irrigation method with appropriate irrigation interval is suitable irrigation method; for semi arid areas.

Alternate furrow irrigation with three days of irrigation intervals will essentially be the best choice under similar conditions of the study area. Thus, it is recommended that all possible efforts should be made to introduce the technology to the farming community and irrigation water use associations since the use of alternate furrow irrigation method saves reasonable amount of water without affecting the production in semi arid area using appropriate varieties of onion crop.

The test crop considered here is onion. But other crops like potato, tomato, cabbage, carrot and hot pepper also grow under irrigation in the region. Hence AFI system should also be tested in other crops too.

Abbreviations

AFI	Alternate Furow Irrigation
EFI	Every Furow Irrigation
FFI	Fixed Furow Irrigation
BCR	benefit-cost ratio
NR	net return

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Author Contributions

Zelalem Shelemew: Conceptualization, Investigation, Methodology, Software, Supervision, Validation, Writing – original draft

Abay Chala: Methodology, Project administration, Visualization, Writing – review & editing

Conflicts of Interest

The authors declare no conflicts of interest.

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