Hindawi
Advances in Agriculture
Volume 2022, Article ID 3587150, 8 pages
https://doi.org/10.1155/2022/3587150

Research Article

Evaluation of Water Productivity under Furrow Irrigation for Onion (*Allium cepa* L.) Crop

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Received 29 January 2022; Accepted 26 June 2022; Published 18 July 2022

Academic Editor: Hitesh Panchal

Irrigation water management practices are the main strategies to improve water productivity. This research work was focused to study the performance of alternate and paired row furrow irrigation systems at three levels of irrigation (100%, 75%, and 50% of crop evapotranspiration) using different water productivity indicators for onion crops. The experiment had six treatments and replicated three times to evaluate the analysis of variance in SAS software. Water productivity indicators like crop water use efficiency, field water use efficiency, and field water expense efficiency were determined through bulb yield and water which were used by the crop. The crop yield was expressed as the total yield of onion bulbs, and crop water use was expressed as crop evapotranspiration (ETc), gross depth of irrigation, and water expense. The estimated maximum values of crop water use efficiency, field water use efficiency, and field water expense efficiency were 11.941, 16.152, and 9.361 kg m^{-3}, respectively, for paired row furrow irrigation with 50% ETc. The performance of the paired row furrow irrigation system in crop yield and water use was better as compared to the alternate furrow irrigation system at all levels of irrigation.

1. Introduction

The water resource was limited by a lot of demand factors [1]. In line with this, agriculture is one of the consumer of this resource for agricultural crop production in the way of irrigation [2]. Irrigation is a source of water for agricultural production improvement to fulfill the growing food demands in the world [3]. The availability of water for irrigation is becoming limited from day to day because of the increasing consumption of water for different sectors such as home and industry. Agriculture is the largest water consumer, but overall irrigation efficiency in the case of surface irrigation at the farmers' fields is very low or insufficient [4, 5]. This water-scarce is a major problem in many areas of the world; in this case, studying the alternative mechanisms to solve the problem is very important [6].

Furrow irrigation is the common surface irrigation method for water application to cropped fields [7]; however, furrow irrigation as practiced by farmers in Ethiopia results in large deep percolation losses and uneven water application [8]. These not only result in large losses of limited water but also create problems of waterlogging and salinity [9]. Therefore, the development of efficient furrow irrigation systems and irrigation water management practices are essential for higher water productivity.

Techniques such as partial irrigation and deficit irrigation can increase or enhance water productivity. When water productivity decreases but irrigation water increases [10], there is an increasing interest to study the crop water productivity of furrow irrigation systems. The study of the water use efficiency of furrow irrigation systems for onion crops is important using deficit irrigation [11].

There are different possibilities of irrigation water applications in furrow irrigation systems. Conventional furrow irrigation (CFI) was the traditional method of furrow irrigation and was widely used by farmers in Ethiopia and any developing country [12–14]. The best water management techniques were alternate furrow irrigation (AFI), fixed furrow irrigation (FFI), and also paired row furrow irrigation (PRFI). The crop planting in the case of PRFI is done at the top of the ridge in paired crop rows [15], and each crop row gets water from side furrows, but the furrow in between the crop rows is not constructed. The spacing between the furrows depends on crop type. The PRFI is similar to fixed furrow irrigation (FFI) in principle with the alternate irrigated furrow in which each irrigation is fixed. The difference is only the furrow spacing and construction of furrow in the case of FFI, but in the case of PRFI, the unirrigated furrow of FFI is not constructed. Thus, the cost of construction of the furrows is reduced; however, many studies have investigated and concluded that AFI is better as compared to CFI and FFI for water productivity [8, 11, 14]. Another option for AFI is there, which is PRFI, but AFI was never compared with PRFI under different irrigation water levels for water productivity throughout the world. Therefore, this study focused on the performance evaluation of AFI and PRFI at different levels of irrigation for water productivity.

2. Materials and Methods

2.1. The Description of Study Area. The field experiment was conducted at Arba Minch University demonstration farmland in the Gamo Zone, SNNPR National Regional State of Ethiopia. The study area is geographically located at an altitude of 1203 m.a.s.l, latitude of 6°04′ N, and longitude of 37°33′ E. The location of the study area is shown in Figure 1.

Based on the data collected from the Arba Minch University Meteorological station, the mean monthly minimum and maximum air temperature in the study area vary from 17.4°C to 30.6°C, respectively. The average annual rainfall in the study area is 750 mm [16], although rainfall is erratic and uneven in distribution. The historical rainfall data show a bimodal behavior with an interval of February up to April and June up to September. The average relative humidity ranges from 39.4% (February) to 62.9% (May), and average annual daily sunshine duration varies from 6.3 hours to 9.1 hours. Based on climate properties of the study area, the agroecological zone of the study area was classified as dry low land [17].

2.2. Preexperimental Activities. To conduct this experimental research, primary and secondary data were collected. Secondary data such as climatic and agronomic data of onion were collected from the Arba Minch University Meteorological station and FAO [18], respectively. The climatic data were maximum and minimum temperature, relative humidity, sunshine hours, wind speed, and rainfall. Other primary data such as soil physical and chemical characteristics were collected.

2.3. Experimental Treatments. The experiment was conducted for alternate furrow irrigation (AFI) and paired row furrow irrigation (PRFI) systems with three levels of irrigation such as 100%, 75%, and 50%. The transplanting after 45 days of seedlings of the Red Bombay variety of onion was done in the ridge and furrow system following recommended agronomic practices.

The treatment plot size for the two systems was 1.6 m × 3 m and the central rows for each treatment were considered experimental rows for the collection of field data. The side rows were nonexperimental (a buffer row) to minimize the border effects, and the plant-to-plant spacing in each row was 10 cm which has a plant density of 30 plants per row. There were 6 treatments; each of the treatments was replicated three times; details of the treatments are given in Table 1. The location of different plots was decided by a randomized complete block design (RCBD). The spacing between each plot to plot and block to block was 1 m and 1.5 m, respectively. The total area required for this experiment was 240.7 m^2 (16.6 m × 14.5 m) (Figure 2).

2.4. Crop Water Requirement Estimation. The onion crop water requirement was estimated from reference crop evapotranspiration (ETo) and crop coefficient (Kc) using equation (1). The ETo was estimated using CROPWAT 8 software based on the Penman–Monteith method for 30-year monthly average climatic data.

$$\mathrm{ETc} = \mathrm{Kc} \times \mathrm{ET_O}. \quad (1)$$

After the determination of crop evapotranspiration using the above relation, the net irrigation requirement (I) was estimated using

$$\mathrm{NIR} = \mathrm{ETc} - \mathrm{Pe} - \mathrm{GW} - \mathrm{SM}, \quad (2)$$

where NIR represents the net irrigation requirement (mm), Pe represents the effective rainfall (mm), GW represents the groundwater contribution (mm), and SM represents the change in soil moisture (mm); the depth of the groundwater table during the crop season was more than 1.6 m; therefore, the groundwater contribution (GW) was negligible.

The gross depth of irrigation water application was expressed as

$$\mathrm{GIR} = \frac{\mathrm{NIR}}{\mathrm{Ea}}, \quad (3)$$

where NIR represents the net depth of irrigation estimated using equation (2) and Ea represents the overall irrigation efficiency measured in the field and found to be equal to 64%.

2.5. Crop Water Productivity. The considered water productivity indicators were crop water use efficiency (CWUE), field water use efficiency (FWUE), and field water expense efficiency (FWEE) as expressed by the following equations [15, 19].

$$\mathrm{CWUE} = \frac{Y}{\mathrm{ETc}}, \quad (4)$$

where CWUE represents the crop water use efficiency (kg m^{-3}), Y represents the crop yield (kg ha^{-1}), and ETc represents the crop evapotranspiration in mm.

$$\text{FWUE} = \frac{Y}{\text{GIR}}, \quad (5)$$

where FWUE represents the field water use efficiency (kg m^{-3}), Y represents the crop yield (kg ha^{-1}), and GIR represents the gross depth of irrigation water application (mm).

$$\text{FWEE} = \frac{Y}{X_P}, \quad (6)$$

where X_p represents the water expense (mm), estimated using the following equation

$$X_P = \text{GIR} + (\omega_{1i} - \omega_{2i})\text{As}_i \times \text{Zr}_i, \quad (7)$$

where ω_1 represents the gravimetric soil moisture at the beginning of the crop growing season (transplanting) (fraction), ω_2 represents the gravimetric soil moisture at the end of crop season (harvesting) (fraction), Zr represents the crop root zone depth (mm), As represents the apparent specific gravity of soil in crop root zone depth, and, i represents the soil layer.

2.6. Data Analysis. The results of onion yield and water productivity were analyzed and subjected to analysis of variance using SAS 9.0 program. The least significant difference (LSD) was used to compare the mean of each treatment. The general framework for this study is shown in Figure 3.

3. Results and Discussion

The soil texture of the soil in the experimental area was determined by using hydrometer analysis, and the field capacity of the soil was also measured by pounding water at the soil surface to saturate the soil column up to about 150 cm soil depth, covering the soil surface with a trace to prevent water evaporation from the soil surface and start measuring soil moisture content after 24 hours. The permanent wilting point of the soil was considered as the soil moisture content at 15 atmospheric tensions. The soil bulk density was calculated by taking undisturbed soil samples in the experimental area. Values of soil physical properties which were measured or determined in the laboratory are given in Table 2.

The important information during each irrigation on intervals of this research work is given in Table 3. The estimated values of seasonal crop evapotranspiration, net and the gross depth of irrigation, water, the expense, and collected value of the total bulb yield for each of the treatments are given in Table 4.

3.1. Statistical Analysis for Total Bulb Yield (TBY). The ANOVA showed that the effect of the furrow irrigation system significantly affected TBY at $P < 0.05$. The maximum TBY (31.204 ton ha^{-1}) was obtained for PRFI and significantly different from the lower TBY (29.445 ton ha^{-1}) obtained in AFI, and in the same way, irrigation levels as the main effect had a significant effect on TBY. Water deficit is one of the essential factors for any crop production [20]. The maximum TBY (37.070 ton ha^{-1}) was obtained at 100% ETc and significantly different for 75% ETc, and the lowest TBY (23.583 ton ha^{-1}) was recorded at 50% ETc. The interaction of the furrow irrigation system and irrigation level significantly affected TBY at $P < 0.05$. As given in Table 5, the maximum TBY (37.863 ton ha^{-1}) obtained for PRFI with 100% ETc (T4) was significantly different from all treatments, and a highly significant difference from the lowest value (23.078 ton ha^{-1}) was obtained for AFI with 50% ETc (T3). The TBY was reduced by 2.64%, 16.38%, 23.46%, 36.38%, and 39.05% for treatments of T1, T5, T2, T6, and T3 when compared to the TBY obtained from T4, respectively. Here, 39.05% of the yield was reduced when 50% of water was saved. The reason for to maximum total bulb yield in T4 is due to a better-wetted root zone rather than deep percolation and soil evaporation loss.

Generally, this result revealed that TBY decreased in both furrow irrigation systems with decreasing irrigation levels. This argues against the results obtained by [21] which reported that the total bulb yield was reduced from 100% ETc to 50% ETc by 3.48 ton ha^{-1}. Similarly, [22] reported that the total bulb yield was reduced from 100% ETc to 50% ETc by 5.66 ton ha^{-1}.

3.2. Water Productivity Indicators. The estimated values of different water productivity indicators using (4), (5), and (6) along with the results of statistical analysis are given in Table 6.

3.2.1. Statistical Analysis for Crop Water Use Efficiency (CWUE). Analysis of variance showed that the furrow irrigation system and irrigation levels significantly affected CWUE at $P < 0.05$. The furrow irrigation system as the main effect, the maximum CWUE (10.596 kg m^{-3}) obtained for PRFI, was significantly different from the lowest value (10.003 kg m^{-3}) obtained for AFI. Similarly, with irrigation level as the main effect, the maximum CWUE (11.691 kg m^{-3}) was obtained at 50% ETc, which was significantly different compared to CWUE recorded at 75% ETc (10.019 kg m^{-3}) and the lowest value (9.188 kg m^{-3}) obtained at 100% ETc.

The interaction effect of the furrow irrigation system and irrigation water level on CWUE was significant at $P < 0.05$. It is observed from Table 6 that the maximum value of CWUE (11.941 kg m^{-3}) was recorded for T6 (PRFI with 50 ETc). The maximum value of CWUE was significantly different compared to all other treatments. Contrary, the minimum CWUE (8.992 kg m^{-3}) was recorded for treatment T1 (AFI with 100% ETc), which was significantly different from all other treatments. On the other hand, there was no significant difference between T2 (AFI with 75% ETc) and T4 (PRFI with 100% ETc).

The CWUE increased as the denominator (water) decreased or CWUE increased as the numerator (yield) increased [23, 24]. This research work agrees with [25] which reported that CWUE decreased as the irrigation level increased. The maximum CWUE for treatment T6 was due to properly managed irrigation water. Contrary, the minimum CWUE for treatment T1 was due to the application of more

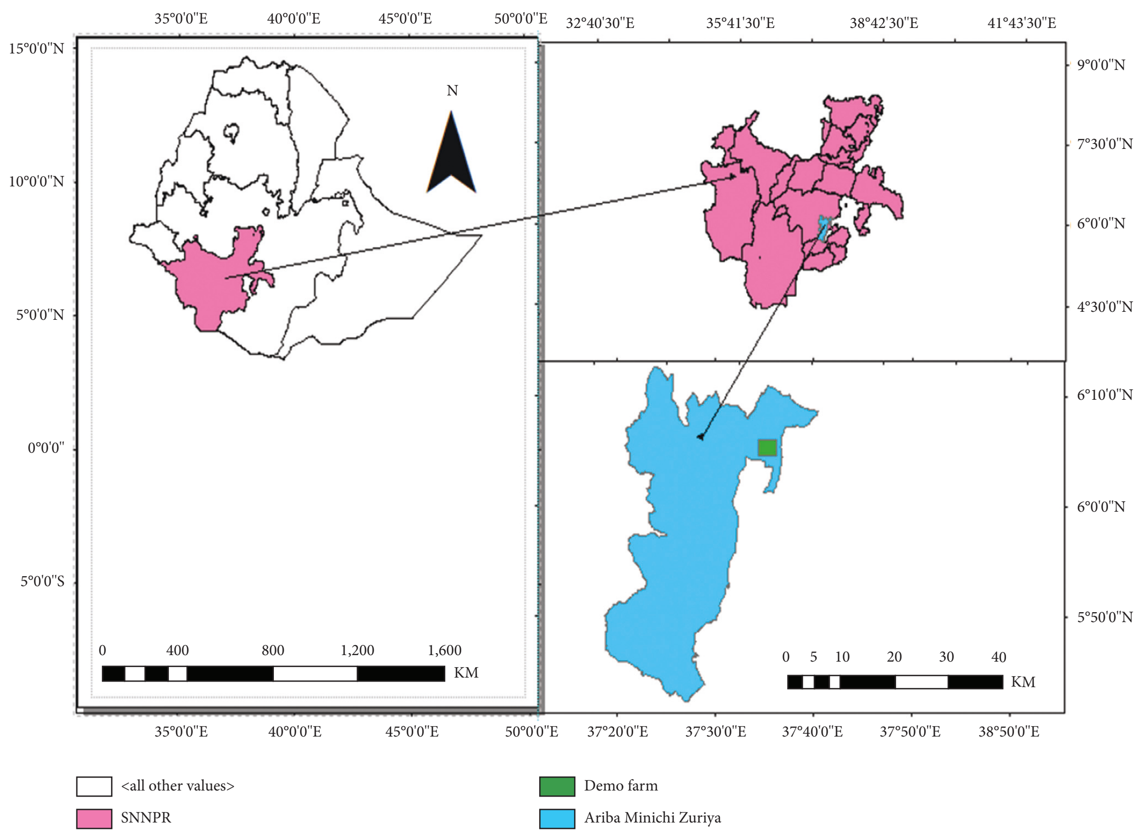

Figure 1: The location map of the study area.

irrigation water that may result in deep percolation or soil water evaporation. Therefore, the PRFI system with a 50% ETc level of irrigation can achieve the maximum CWUE. It results in 50% water-saving compared to full irrigation treatment (100% ETc). The irrigation water so saved may be used to bring more area under production. Therefore, areas having water-scarce should use a paired row furrow irrigation system to maximize crop water productivity rather than maximizing crop yield per unit area.

Table 1: Treatment combinations of different furrow irrigation systems with level of irrigation water.

Furrow irrigation system	Alternate furrow irrigation (AFI)			Paired row furrow irrigation (PRFI)		
Treatment	T1	T2	T3	T4	T5	T6
Deficit level of irrigation as ETc (%)	100	75	50	100	75	50

3.2.2. Statistical Analysis of Field Water Use Efficiency (FWUE). Analysis of variance showed that the furrow irrigation system and irrigation levels significantly affected FWUE at $P < 0.05$. The furrow irrigation system has the main effect; the maximum FWUE (12.121 kg m^{-3}) obtained for PRFI was significantly different from the lowest value (11.452 kg m^{-3}) obtained for AFI. Similarly, with irrigation level as the main effect, the maximum FWUE (15.813 kg m^{-3}) obtained at 50% ETc was significantly different compared to FWUE obtained at 75% ETc (10.811 kg m^{-3}) and the lowest value (8.736 kg m^{-3}) obtained at 100% ETc.

The interaction effect of the furrow irrigation systems and irrigation water levels on FWUE was significant at $P < 0.05$. It was observed from Table 5 that the maximum value of FWUE (16.152 kg m^{-3}) was obtained for treatment T6 (PRFI with 50% ETc). This maximum value of FWUE was significantly different compared to all other treatments. The minimum FWUE (8.549 kg m^{-3}) was recorded for treatment T1 (AFI with 100% ETc).

On the other hand, there was no significant difference between T1 (8.549 kg m^{-3}) and T4 (8.922 kg m^{-3}) for both treatments with a 100% level of irrigation. However, FWUE was slightly higher for treatment T4 (PRFI) compared to T1 (AFI). It indicates that PRFI had higher crop productivity performance compared to the AFI system (Table 5).

The results revealed that FWUE increased as irrigation water decreased (Table 6). The reason to obtain the maximum FWUE for treatment (T6) was the lesser gross irrigation depth compared to other treatments except for treatment T3. The FWUE for treatment T6 (PRFI with 50% ETc) was higher compared to treatment T3 (AFI with 50% ETc). Therefore, in areas of limited water resources, PRFI was preferable to AFI with 50% ETc to maximize FWUE. The saved water may be used to bring more area under irrigation

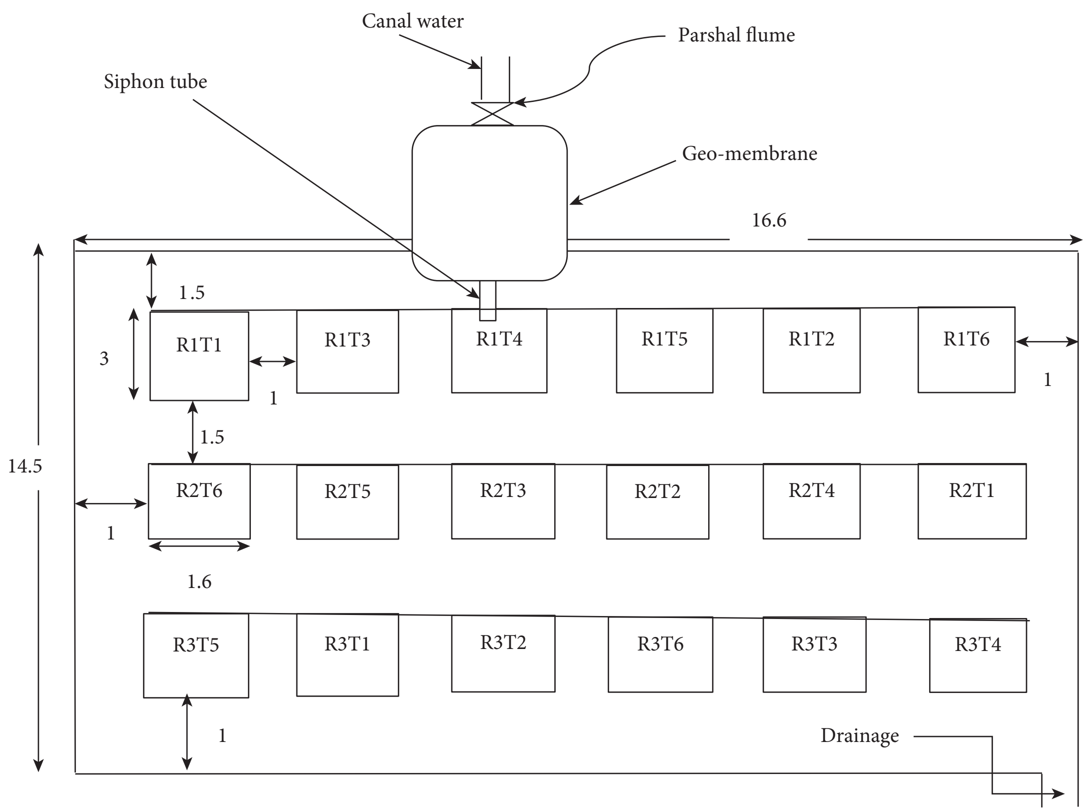

Figure 2: A general block framework illustrating the experimental design and field layout (all dimensions are in meters) (*R*, replication; *T*, treatment).

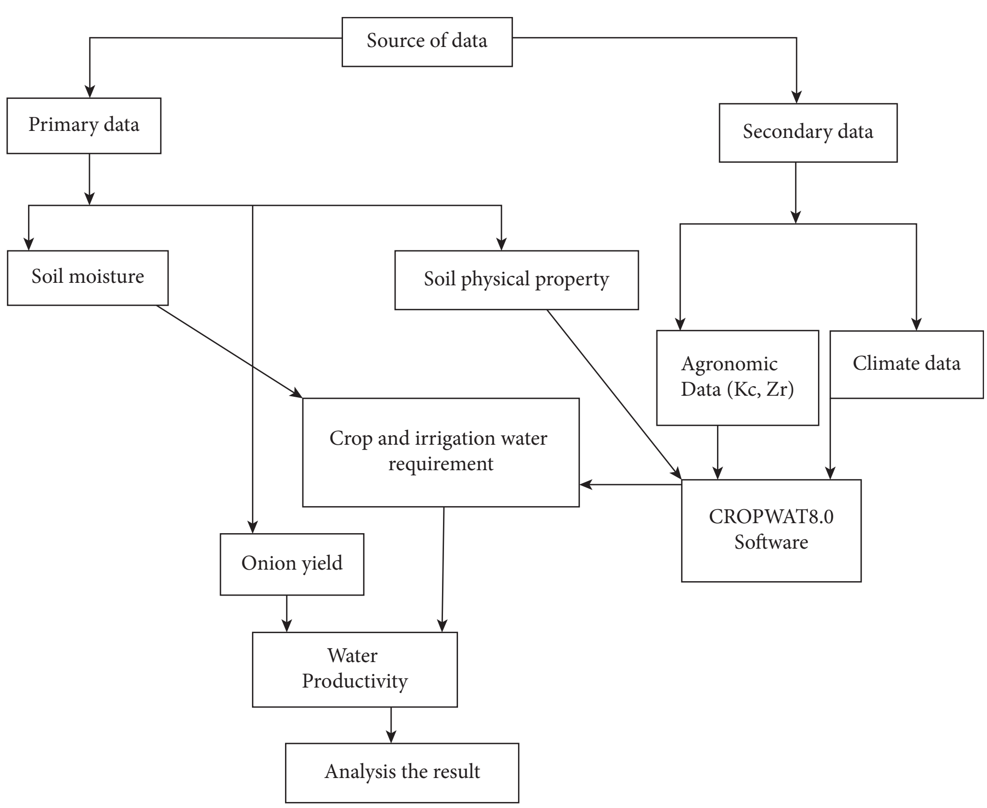

Figure 3: A general flowchart depicting the methodology of the study.

Table 2: Average values of soil physical properties.

Soil texture	Bulk density (g cm^{-3})	Field capacity (fraction)	Permanent wilting point (fraction)	Total available water (mm)
Silty clay	1.26	0.36	0.201	0.159

Table 3: Reference crop evapotranspiration, crop evapotranspiration, rainfall, and effective rainfall during different irrigation intervals.

Irrigation interval	ETo (mm)	Kc	ETc (mm)	Rain fall (mm)	Effective rainfall (mm)
09–14 August	22.45	0.70	15.72	18.20	8.33
14–20 August	23.44	0.70	16.41	0.00	0.00
20–26 August	24.18	0.70	16.93	3.90	3.90
26–1 September	24.03	0.75	17.94	14.60	14.60
1–7 September	25.38	0.82	20.73	11.80	10.30
7–13 September	25.94	0.89	23.00	0.00	0.00
13–19 September	25.80	0.96	24.68	2.00	2.00
19–25 September	25.15	1.03	25.82	2.40	2.40
25–1 October	24.95	1.05	26.20	9.30	9.30
1–7 October	25.21	1.05	26.47	77.90	26.47
7–13 October	24.52	1.05	25.75	44.60	17.20
13–19 October	24.07	1.05	25.27	10.90	5.40
19–25 October	24.14	1.05	25.35	17.40	9.60
25–31 November	24.02	1.05	25.22	5.00	5.00
31–6 November	24.69	1.05	25.92	6.00	4.80
6–12 November	24.30	0.95	23.09	10.90	6.20
12–18 November	24.14	0.85	20.52	8.50	3.40
18–24 November	24.61	0.75	18.46	0.00	0.00
Total	441.02		403.4627	243.4	128.9

Table 4: Important values of the collected data for each treatment.

Treatment	ETc (mm)	NIR (mm)	GIR (mm)	X_p (mm)	TBY (ton ha^{-1})
T1	403.46	274.56	424.36	476.3	36.278
T2	302.6	181.46	280.46	381	28.981
T3	201.73	96.49	149.14	258.9	23.078
T4	403.46	274.56	424.36	472.6	37.863
T5	302.6	181.46	280.46	385.1	31.659
T6	201.73	96.49	149.14	257.6	24.089

or for other commercial uses like domestic water supply for drinking or industrial use.

Corresponding to this, [22] concluded that water productivity was maximum at a medium level of a deficit than higher soil moisture availability (full irrigation water availability); similarly, [26] reported that water use efficiency decreased with increased water supply.

3.2.3. Statistical Analysis for Field Water Expense Efficiency (FWEE). The interaction effect of the furrow irrigation system and irrigation water levels on FWEE was significant at $P < 0.05$. As it is observed in Table 6, FWEE was slightly higher (9.361 kg m^{-3}) for treatment T6 (PRFI with 50 ETc) compared to all other treatments. This maximum FWEE was significantly different compared to all other treatments. The minimum FWEE (7.619 kg m^{-3}) was recorded for treatment T1 (AFI with 100% ETc) which was not a significant difference between T2 (7.68 kg m^{-3}) and T4 (8.014 kg m^{-3}). Furthermore, there was no significant difference between T4 and T5.

As shown in the result field, water expense efficiency was decreased with an increase in water expense. The differences in FWEE between treatments were very small due to soil moisture during transplanting being the same for all treatments, but during harvesting, different soil moisture for each treatment was collected. Practically, the amount of applied irrigation water for 100% ETc was different from 75% ETc and 50% ETc. Similarly, the soil moisture was also different for different treatments. That means the maximum soil moisture was observed for 100% ETc treatment less than 75% ETc and 50% ETc at the time of harvesting. This maximum soil moisture for 100% ETc was subtracted from soil moisture during transplanting (uniform value) to get a smaller value than 75% ETc and 50% ETc. Therefore, the depth of water expense becomes counterbalancing with the decreased gross depth of irrigation. Generally, FWEE was increased when irrigation water decreased [19].

Generally, water productivity was affected by different factors. In line with this, [25] reported that water productivity was affected by the furrow irrigation system, irrigation water level, crop yield potential, and climatic conditions of the crop grown region. In the same way, [27] reported that water productivity was increased by improving yield or reducing irrigation water. Anyways, in the present research,

Table 5: Effect of furrow irrigation systems with irrigation levels on the total bulb yield (ton ha^{-1}).

Furrow irrigation systems	Irrigation levels 100	75	50	Mean
AFI	36.278^{b*}	28.981^{d}	23.078^{f}	29.4457
PRFI	37.863^{a}	31.659^{c}	24.089^{e}	31.2037
Mean	37.0705	30.32	23.5835	
LSD (0.5)			0.784	
CV (%)			1.42	

*Means followed by different letters were significantly different at $P < 0.05$.

Table 6: Effect of furrow irrigation systems with irrigation levels on water productivity.

Furrow irrigation systems	Irrigation levels	Water productivity indicators (kg m^{-3}) CWUE	FWUE	FWEE
AFI	100% ETc	8.992^{e*}	8.549^{e}	7.619^{d}
	75% ETc	9.577^{d}	10.333^{d}	7.680^{d}
	50% ETc	11.439^{b}	15.474^{b}	8.914^{b}
PRFI	100% ETc	9.385^{d}	8.922^{e}	8.014^{cd}
	75% ETc	10.462^{c}	11.288^{c}	8.221^{c}
	50% ETc	11.941^{a}	16.152^{a}	9.361^{a}
	LSD (0.05)	0.330	0.431	0.408
	CV	1.760	2.009	2.704

*Means followed by different letters were significantly different at $P < 0.05$.

the paired row furrow irrigation system resulted in maximum water productivity (CWUE, FWUE, and FWEE) with decreased irrigation water level (deficit irrigation condition) at 50% ETc. This method is very important in the area of water scarcity [16].

4. Conclusion

Water management in the furrow irrigation system was essential for the improvement of water productivity. Evaluation of water productivity under different furrow irrigation systems is important to identify the suitable furrow irrigation system with optimum levels of irrigation water.

In the present research, water productivity under alternate furrow irrigation and paired row furrow irrigation systems at three levels of irrigation water were studied. The crop water requirement was estimated using CROPWAT 8.0 software. The experiment was designed as a two-factorial and becomes six treatment and replicated three times. Statistically, the mean of collected data was separated using LSD at a 5% probability level in SAS software, and the effect of treatment was tested using bulb yield and water productivity indicators.

The water productivity evaluation indicators were crop water use efficiency, field water use efficiency, and field water expense efficiency. The estimated values of crop water use efficiency, field water use efficiency, and field water expense efficiency varied 8.992–11.439 kg m^{-3}, 8.549–15.474 kg m^{-3}, and 7.619–8.914 kg m^{-3} for the alternate furrow irrigation system and 9.385–11.941 kg m^{-3}, 8.922–16.152 kg m^{-3}, and 8.014–9.361 kg m^{-3} for the paired row furrow irrigation system as irrigation level varied from 100% ETc to 50% ETc, respectively.

Therefore, the new outcome in this research was the paired row furrow irrigation system was identified with better performance than an alternate furrow irrigation system in water-saving, crop yield, and water productivity for onion crops. Therefore, the use of the paired row furrow irrigation system is recommended for practicing irrigation. Further studies will be needed for spatial and temporal evaluation of water productivity under two methods with different crops.

Data Availability

All the available data can be accessed through request.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

Acknowledgments

The authors would like to thank Arba Minch University for allowing to do this research. The authors also thank Mrs. Shashe Shita for motivating in performing this experimental work.

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