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IMPACT OF SURFACE IRRIGATION MANAGEMENT ON WHEAT YIELD AND QUALITY PARAMETERS IN EGYPT

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Abstract

This research was conducted at El-Gemmeiza Agricultural Research Station, Gharbia Governorate, middle of the Nile Delta, Egypt, during the winter seasons of 2021/2022 and 2022/2023 to determine the effect of different bed-furrow irrigation management strategies on irrigation efficiency, wheat grain yield and its components and quality parameters. The field experiment was designed in RCBD and included: basin-flooding (control, Tf) and bed-furrow with three irrigation times as a percentage of advance time (Ta); T1=Ta,T2=1.20Ta, and T3=1.30Ta. The results revealed that; increasing irrigation time had a simple effect on the Ta while had an obvious effect on the depletion and recession time. The T1 saved 23.3% of irrigation water compared to the Tf, increasing irrigation time increased water applied. The soil moisture content in the Tf was higher than in the bed-furrow treatments. Increasing irrigation time increased the moisture content in the furrows and within the beds. Bed-furrow enhanced irrigation efficiency compared to Tf. The highest application efficiency and distribution uniformity values were 76.6, 74.7 and 80.7, 82.3%, which were achieved by T3 treatment. Bed-furrow increased wheat grain yield compared to Tf. The T3 treatment is superior in grain yield with values of 3107 and 3185 kg fed^{-1}.Bed-furrow enhanced the 1000 grain weight and spike length, while Tf surpassed in the number of spikes and straw yield. The highest water productivity was 1.87 and 1.67 kg m^{-3} achieved by T1. There is no significant difference in quality parameters except for dry gluten, the highest values achieved by T2 treatment.

Key words**:** *bed-furrow, storage phase, irrigation efficiency, wheat*

INTRODUCTION

Choosing an appropriate irrigation method has a vital role in crops production and the sustainability of water resources. Since water has become one of the most significant elements in crop production, it should be utilized efficiently to provide the optimum yield [1]. Furrow irrigation is a common method of irrigating crops in developing countries; it is particularly recommended for cultivating row crops in soils of medium to heavy texture, and it is favored over the flooding method because of its ease of use and low capital cost [8]. In this regard, the basin-flooding irrigation method (F) for wheat in the Nile Delta in Egypt causes excessive application losses and encourages water logging, while the bed-furrow irrigation method commonly defined as raised beds (B) improves irrigation efficiencies and wheat productivity [11, 20, 24]. Replacing the (F) method with the (B) method is considered one of the innovative solutions to address water scarcity in Egypt. Furrow irrigation is recommended in clay soil and is preferred over flooding irrigation method because it saves irrigation water and raises wheat grain yield [18] The optimum management of the furrows under bed sowing should ensure good lateral movement of the irrigation water to the bed center for getting a proper grain yield and water productivity, the lateral movement of irrigation water to the bed center is one of the main determinants of bed width [4]. Suboptimal bed width causes insufficient lateral movement of irrigation water to its center, resulting in poor crop germination and water productivity [3]. Wide beds have advantages in that they reduce drainage losses, crop productive area losses, and irrigation water saving, however, the wide beds are defective with poor lateral infiltration and, thus, poor yield for rows in the middle.

Therefore, optimal irrigation practices such as over irrigation of the beds in the initial growing stages are essential to encourage lateral infiltration. However, due to a lack of knowledge and the absence of appropriate guidelines, such management has been uncommon in field conditions to date [2, 5]. A comprehensive understanding of how wheat responds to irrigation timing encourages better management of the irrigation system, enhancing positive effects and minimizing unfavorable effects on grain yield and quality [25]**.** As indicated by [6], many researchers divided the surface irrigation process into four phases: Tad, advance; Ts, storage or wetting; Td, depletion; and Tr, recession. Advance phase refers to the movement of the water stream from the upstream end of the field towards the downstream end; this phase is complete once the water stream reaches the field's downstream end. The storage phase begins after the water has reached the downstream end, as the flow continues to collect in the field. The storage phase ends when the inflow is cut off, after which the depletion phase occurs and remains until the surface waters disappear at the upstream end. The recession phase occurs when surface water disappears from the upstream end and finishes when no irrigation water remains on the soil surface. The [10] referred to the behavior of some quality traits under deficit irrigation: gluten, kernel hardness, and falling number decreased while protein content increased. The proper combination of irrigation practices and genotypes is necessary to produce winter wheat with adequate grain yield and quality indices. According to many researchers, such as [13] increased protein and wet gluten content are obtained under full irrigation, while others, such as [21] found the opposite. Irrigation water regime had a significant effect on grain yield, protein content, and grain hardness, reducing the irrigation regime from 100 to 30% of ETc decreased grain yield and increased protein content; the raise in protein content was most likely a function of grain yield shortage resulting from water stress [23]**.** The applied irrigation strategy is a determinant factor in identifying wheat grain quality [15]. The impact of four irrigation regimes (I1=25%, I2= 50%, and I3= 75%) on the maximum allowable depletion of available soil moisture and I4 = 4 events in the four growth stages on wheat grain quality was investigated in sandy loam soil under semi-arid conditions. The hectoliter weight, protein content, and wet and dry gluten content were significantly affected by irrigation regimes, while grain hardness non significantly affected. The highest hectoliter weight was 81.5 kg/hL for treatment I1, the highest protein and wet and dry gluten content were 13.4 and 34.0, and 11.79 %,respectively, which were obtained by I3 treatment. The highest grain hardness was 83.26%, found by I3 treatment [19]**.** The differences in grain quality among sixteen wheat genotypes under stress and full irrigation were evaluated. A significant reduction in 1,000-grain weight (g) and hectoliter (kg/hL) caused by water stress, while protein and gluten contents (%) increased at the same conditions [21]. Therefore, the purpose of this study was to improve the irrigation performance, wheat grain yield, and quality traits of the bed-furrow irrigation method and to identify the optimal strategies for this.

MATERIALS AND METHODS

Field description

A field experiment was carried out in El-Gemmeiza Agricultural Research Station, Gharbia Governorate, middle of the Nile Delta, Egypt, during the winter growing seasons 2021/2022 and 2022/2023. The site was located at 31° 07′ longitude, 30° 43′ latitude, and 20 m mean altitude above sea level. Some climatic data, such as maximum and minimum air temperatures; T, wind speed; WS, relative humidity; RH, and monthly total rainfall, mm for growing seasons recorded by the Central Laboratory for Agricultural Climate (CLAC), Agricultural Research center, Table 1.

Soil samples from three layers (0-20, 20-40 and 40-60 cm) were collected from three sites of the experimental field. The soil was characterized as clay, the mechanical analysis and some physical properties were analyzed by the Soils, Water and Environmental Research Institute Laboratory, El-Gemmeiza Agricultural Research Station, Table 2.

Table 1. Meteorological data for the experimental site during the two growing seasons

Month	T_{mini},°C	T_{max}, °C	RH, %	WS m/sec	Rainfall mm
First season 2021/2022					
Nov.	16.5	28.7	66.1	2.2	6.3
Dec.	10.9	20.3	71.6	2.6	12.0
Jan.	7.0	17.6	71.2	2.5	26.2
Feb.	8.0	19.9	70.1	2.3	20.8
Mar.	8.2	20.8	65.3	2.8	22.8
Apr.	13.2	30.8	56.2	2.9	0.7
Second season 2022/2023					
Nov.	15.4	26.8	60.5	2.2	3.2
Dec.	13.1	24.2	67.2	2.1	23.5
Jan.	10.2	21.7	69.2	2.1	6.4
Feb.	8.8	20.7	61.5	2.5	7.2
Mar.	12.4	27.0	52.1	2.9	15.7
Apr.	13.9	30.1	50.0	2.9	2.3

Source: Central Laboratory for Agricultural Climate (CLAC), Agricultural Research center, Egypt.

Table 2. Mechanical analysis of the experiment site

Soil depth, cm	Particle size distribution			Bd, g/cm^3	FC, %	PWP, %
	Clay, %	Sand, %	Silt, %			
0-20	50.67	14.52	34.81	1.10	45.60	24.30
20-40	53.09	11.00	35.9	1.15	40.90	21.55
40-60	52.76	10.63	36.61	1.34	38.20	19.80

Bd: Bulk density, FC: Field capacity, PWP: Permanent wilting point
Source: Own calculation.

The field was prepared using the traditional seed bed preparation method (Chiseling twice + traditional leveling). Wheat (variety Giza 171) was drilled at a distance of 15 cm between rows in November and harvested in May; the field length is 50 m without dikes and with a closed end. For bed treatments; the beds were raised at a distance of 130 cm between beds with a 100 cm net bed width. Furrow dimensions were top width 30 cm, bottom width 10 cm and depth 15 cm. All agricultural practices have been applied. Wheat was irrigated 4 irrigations in the season (planting + 3 irrigations; an event at every growing stage) as recommended by [12].

Irrigation system

Perforated pipes network were used for irrigation, it consists of aluminum pipes with 75 mm diameter and 6 m length joined together by quick coupler. The orifices were distributed at a distance equal to the distance between furrows (130 cm).The discharge rate was controlled by 32 mm valve and male adaptor (32 X 3/4") installed at every orifice by a saddle (75 X 32 mm). A centrifugal pump with 3" inlet and outlet diameters was used to transfer the water to the pipes. The discharge rate was calibrated at 1.0 L s^{-1}. Discharge rate was measured by the volumetric method as explained by [17].

Experimental design

Four treatments with three replicates were arranged in a randomized complete block design in the two growing seasons: a control treatment viz basin-flooding irrigation method (Tf) and bed-furrow irrigation method with three irrigation patterns: irrigation to the end of the furrow (irrigation time = advance phase; T1), irrigation to the end of the furrow + storage phase equal 20% of advance time (irrigation time = 1.20 advance phase; T2) and irrigation to the end of the furrow + storage phase equal 30% of advance time (irrigation time = 1.30 advance phase; T3). Each replication included five furrows and four beds. The Co-Stat program for windows was utilized to analysis of variance (ANOVA), the mean of results for different treatments were compared at the 5% significance level.

Measurements

Inlet flow rate, irrigation phases and water applied: The orifices flow rate was calibrated at 1.0 L s^{-1} per furrow for bed-furrow treatments and per 1.3 m width in Tf treatment (2.77 m^2 h^{-1} discharge rate per unit width). The advance time (Tad) along the field was recorded at 10 stations (each 5 m). The storage time (Ts) as a percentage of the Tad according to every treatment was recorded. After irrigation cut-off the depletion time (Td) and the recession time (Tr) along the field at the same 10 stations were recorded. Applied irrigation water per event was measured as well as the seasonal water applied. The Tad and Tras the function of the furrow length (L) were formatted in an empirical power equations [22] as follows:

$T_{ad} = a L^m$ .... (1)

$T_r = c L^x$ .... (2)

where:
a and m are empirical advance coefficients, and c and x are empirical recession coefficients.

Soil moisture content: It was measured gravimetrically at three depths (0-20, 20-40 and 40-60) cm at the furrow center, and bed center. The soil samples were collected every 10 m along the field prior to irrigation and at field capacity. The soil moisture content was calculated using Eq. 1 according to [27]:

$\theta_m = (M_w/M_d) * 100$........................... (3)

In which: θ_m is soil moisture content on a dry mass basis (%), M_w is mass of water within the soil sample (g) and M_d is dry mass of dry soil (g).

Application efficiency (Ea, %): it indicates the beneficial utilization percentage of the water applied. It is calculated by Eq. 4 according to [17].

$E_a = (RZ/\forall) * 100$.............................. (4)

where:
RZ is amount of water stored in the root zone and ∀ is total water applied.

Distribution uniformity (DU, %): It describes how precisely the system distributes water evenly along the field. DU is defined as low quarter distribution uniformity and calculated by Eq. 5 according to [17].

$DU = (x^{\backslash}_{LQ}/x^{\backslash}) * 100$............................ (5)

where:
$x^{\backslash}_{LQ}$is low-quarter average depth infiltrated and $x^{\backslash}$ is average depth infiltrated.

Wheat grain yield, its components, and straw yield: At harvesting, wheat grain yield; kg fed^{-1}, some yield components include 1,000 grain weight; g, spike length; cm, and number of spikes m^{-2} and the straw yield; kg fed^{-1} were calculated.

Water productivity (WP, kg m^{-3}): It shows the change in crop yield related to irrigation management strategies. It calculated according to [17] as follows:

$$WP = \frac{Total\ grain\ yield, kg/ha.}{Total\ applied\ irrigation\ water, m^3/ha.}$$

.... (4)

Quality parameters

After harvesting the second season (2022/2023), random grain samples were collected from each treatment to assess quality parameters performed in the Food Technology department, faculty of agricultural Kafr El-Sheikh University and Rice Mechanization Center (RMC) Laboratory, Meet El-Deyba, Kafr El-Sheikh Governorate, Egypt. Test weight or hectoliter mass (HLM, kg $100L^{-1}$) defines the grain's bulk density and indicates the potential percentage of milling extraction. It is an important wheat grading factor [9] and some cultivars might have the ability to always have higher HLM than others grown under similar conditions. A higher HLM indicates a well-filled wheat grain.HLM was obtained by filling a 100 ml measuring cylinder with wheat grain, weighing it, and expressing it in kg $100L^{-1}$ [7]. Kernel hardness refers to the ability of a kernel to resist breaking under pressure and directly affects the yield of flour. It was measured using a digital grain hardness tester (Model: AGW).The protein is the most important component of wheat grain ranged from 8 to 15% on weight basis. it is a reference index for evaluating the high quality of strong gluten wheat. It depends on genetic and environmental factors [14]. The protein percentage (%) had been determined using the Kjeldahl method, as defined by [7], Method 46-13, and the factor 5.7 to convert the nitrogen value in to total protein. The protein concentration in wheat grain depends on genetic and environmental factors [14]. Wet gluten percentage (%) was evaluated using the hand-washing method (AACC 38-10.01), and dry gluten percentage (%) was produced after oven-drying the dough at 105 °C for 6 hours [7]. The falling number (FN) value expresses the speed required to move a hot aqueous starch gel subjected to liquefaction at a constant temperature of 100°C in a viscometer and then let the viscometer initiator fall a certain distance via the gel [7].

RESULTS AND DISCUSSIONS

Irrigation phases

The data showed that Tf treatment had a longer advance compared to bed-furrow treatments, where the average Tad was 164 min for Tf treatment, this finding is in agreement with many researchers as [2]. The average irrigation phases for the two growing seasons and the three events per season for the bed-furrow treatments are shown in Fig. 1.The (Tad) for the three treatments T1, T2, and T3 were 100, 98 and 95 min, respectively. This means the existence of the storage phase had a simple effect on the advance time, possibly because the effect of the storage phase began with the third event and was more pronounced with the last event; on the contrary, it had an obvious effect on the depletion and recession time. The T1 treatment recorded a 13 min depletion time Td and a 90 min recession time Tr, the presence of 20% storage time Ts in the T2 treatment, increased Td and Tr by about 53.8 and 50.0%, respectively. In the T3 treatment, where Ts = 30% Tad, The depletion time Td and recession time Tr recorded 25 and 170 min respectively which increased by about 92.3 and 88.9 %, respectively compared to the T1 treatment. The empirical power equations for advance and recession phases for the three bed-furrow treatments described as follow:

T1:-

$Tad = 0.25\, L^{2.57}$ $\quad R2 = 0.95$

$Tr = 102.3\, L^{0.26}$ $\quad R2 = 0.92$

T2:-

$Tad = 0.37\, L^{2.54}$ $\quad R2 = 0.90$

$Tr = 121.7\, L^{0.30}$ $\quad R2 = 0.91$

T3:-

$Tad = 0.09\, L^{3.16}$ $\quad R2 = 0.84$

$Tr = 133.6\, L^{0.32}$ $\quad R2 = 0.91$

Water applied

Water applied per event for different treatments for the two growing seasons (m3/fed.) is shown in Fig 2. In planting irrigation; bed-furrow irrigation treatments consumed irrigation water more than basin-flooding irrigation treatment (Tf) by about 36.7 and 23.3% for the two growing seasons, respectively.

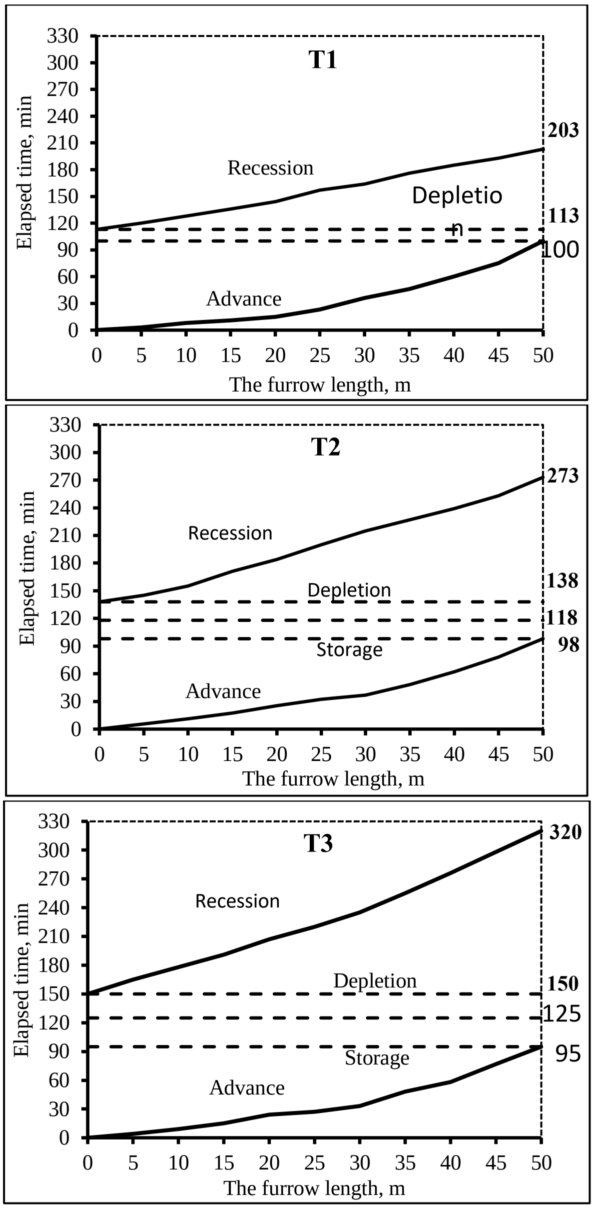

Fig. 1. Surface irrigation phases for bed-furrow treatments
Source: Own calculation based on experimental data.

This finding could be attributed to that in the Tf treatment, the irrigation water advanced directly above the soil surface from the upper to the lower end of the field, and irrigation was stopped (advance phase only), while in bed-furrow irrigation water was transported along the furrows (advance phase), then continued (storage/filling phase) until the beds were completely submerged with irrigation water to promote optimal seed germination. Inbed-furrow, the advance phase accounted for 20% of total irrigation time, while the storage/filling phase accounted for 80%. For the subsequent irrigations, (Tf) utilized more irrigation water than bed-furrow treatments, where the whole field is irrigated; also, increasing the plant growth and density creates an obstacle to the advancement of water in the field, while in bed-furrow the soil is partially irrigated through paths prepared for this. Increasing the storage phase in the bed-furrow treatments increased the amount of the water applied. Water applied for each event increased compared to the previous event; increasing air temperature and weed growth in the furrows had an impact on bed-furrow treatments. The amount of water applied was influenced by the variation in rainfall throughout the two growing seasons.

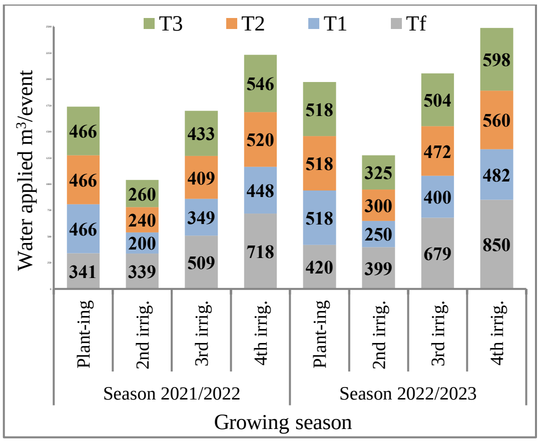

Fig. 2. Water applied per event during the two growing seasons.
Source: Own calculation based on experimental data.

The average seasonal water applied (m^3/fed.) for the different treatments are listed in Table 3. The results showed that there was a highly significant difference in the total water applied between the different irrigation treatments. Bed-furrow treatments T1, T2, and T3 saved irrigation water compared to Tf treatment by about 23.3, 14.3 and 10.5 % and 29.7, 21.2 and 17.1 %, for the two growing seasons, respectively.

This result is consistent with that obtained by several researchers [5, 18]. The application of 20 and 30 % storage phase in the T2 and T3 treatments increased the water applied by about 12.1 and 17.9 % compared to the T1 treatment.

Table 3. Average seasonal water applied for the different treatments.

Treatment	Water applied, m^3 fed^{-1}	
	2021/2022	2022/2023
Tf	1907 a	2347 a
T1	1463 c	1650 c
T2	1634 b	1850 b
T3	1706 b	1945 b
LSD 0.05	92.0	146.0

Means followed by the same letter in the same column are not significantly different at the $p \leq 0.05$ level.
fed. = 4,200 m^2
Source: Own calculation based on experimental data.

Soil moisture content

The averages of soil moisture content in the bed center and furrow bottom at field capacity are showed in Fig. 3. The results revealed that the soil moisture content in the Tf treatment was higher than in the bed-furrow treatments, where the soil was completely submerged with water, as well as fewer evaporation losses from the soil surface due to the high density of plants. The moisture content of the Tf treatment exceeded the field capacity, which means an increase in irrigation water loss and a decrease in irrigation efficiency. For the bed-furrow treatments, the existence of storage time had a positive effect on the moisture content in the furrows and within the beds. The storage phase promotes the lateral movement of the irrigation water and thus raises the moisture content within the beds. The moisture content in the surface layer (0-20) cm in the furrow increased from 38.6% for T1 to 39.8% for T2 and 42.2% for T3 and increased in the center of the bed from 35.5% for T1 to 37.7% for T2 and 39.3% for T3. The same trend is observed for the subsequent two layers.

Application efficiency (Ea, %) and distribution uniformity (DU, %)

The average application efficiency (Ea, %) and distribution uniformity (DU, %) for the different treatments are listed in Table 4. The statistical analysis showed a significant effect of irrigation treatments on application efficiency and distribution uniformity at a 95% probability level.

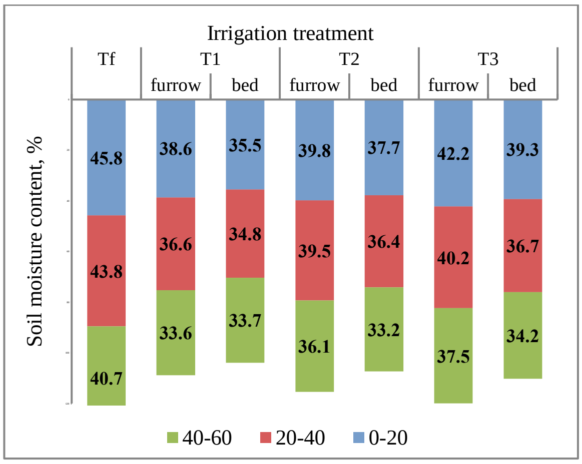

Fig. 3. Soil moisture content in the bed center and furrow bottom at field capacity
Source: Own calculation based on experimental data.

Table 4. Average application efficiency and distribution uniformity for different treatments

Treat.	Ea, %		DU, %	
	2021/022	2022/023	2021/022	2022/023
Tf	64.7 b	60.0 c	69.2 c	70.5 c
T1	71.7 a	66.6 b	73.3bc	75.2bc
T2	72.8 a	69.5 b	77.9 ab	77.5 ab
T3	76.6 a	74.7 a	80.7 a	82.3 a
LSD 0.05	5.3	4.9	5.5	5.6

Source: Own calculation based on experimental data.

Bed-furrow treatments enhanced the Ea and DU compared to flat sowing in the two growing seasons; the same results were obtained by [2]. The existence of the storage phase had a positive effect on the Ea and DU where stored water increased. The highest Ea values for the two growing seasons were 76.6 and 74.7% for treatment T3 followed by 72.8 and 69.5% for treatment T2; while Tf gave the lowest values of 64.7 and 60.6%. It was observed that there is no significant difference in the Ea values between bed-furrow treatments in the first season. The T3 treatment achieved the highest DU with values of 80.7 and 82.3% followed by the T2 treatment with values of 77.9 and 77.5% while the Tf treatment gave the lowest values of 69.2 and 70.5%. There is no significant difference in the value of DU between treatments T3 and T2 and between treatments T2 and T1.

Wheat grain yield

The averages wheat grain yield for different treatments are listed in Table 5.The analysis of variance indicated that irrigation treatment had a significant effect on wheat grain yield at the 95% probability level. Raised bed increased wheat grain yield compared to flat sowing in the two growing seasons; the same findings were obtained by [3, 5]. Bed-furrow treatments T1, T2 and T3 increased wheat grain yield compared to Tf treatment by about 22.6, 27.1 and 39.3 % and 13.8, 15.5 and 31.6 % for the two growing seasons, respectively. Increasing the storage phase leads to an increase in wheat grain yield where the lateral infiltration in the middle zone of the bed is enhanced. The T3 treatment is superior in grain yield compared to the other treatments. It achieved 3,107 and 3,185 kg fed^{-1} for the two growing seasons, respectively.

Table 5. Average wheat grain yield for different treatments

Treat.	Grain yield, kg fed^{-1}		Water productivity, kg m^{-3}	
	2021/022	2022/023	2021/022	2022/023
Tf	2,230 b	2,421 b	1.17 b	1.03 b
T1	2,734 a	2,755 a	1.87 a	1.67 a
T2	2,835 a	2,796 a	1.74 a	1.51 a
T3	3,107 a	3,185 a	1.82 a	1.64 a
LSD 0.05	501.0	627.0	0.44	0.39

Means followed by the same letter in the same column are not significantly different at the $p \leq 0.05$ level.
fed. = 4,200 m^2
Source: Own calculation based on experimental data.

Yield components and straw yield

The averages for some yield components, including the 1,000 grain weight; g, spike length; cm, and the number of spikes m^{-2} and straw yield; kg fed^{-1} for different treatments, are listed in Table 6. The statistical analysis showed a significant effect of irrigation treatments on the 1,000 grain weight, spike length, and straw yield in the first season, while there was no significant effect on the number of spikes m^{-2} and straw yield in the second season. The results showed that bed-furrow irrigation enhanced the 1,000 grain weight and spike length while, basin-flooding irrigation surpassed in the number of spikes and straw yield. The superiority of basin-flooding in the number of spikes m^{-2} and straw yield is due to the fact that, in basin-flooding irrigation, the field is cultivated completely since there are no area losses due to furrows, as in bed-furrow irrigation. The existence of the storage phase enhanced the yield components and straw yield. There is no significant difference in the 1,000 grain weight between bed-furrow treatments, and the highest value was 72.5 and 80.0 g for the two growing seasons, which was achieved by the T3 treatment. The difference in spike length between bed-furrow treatments was significant in the first growing season only; the highest values were 13.0 and 13.2 cm for the two growing seasons achieved by T3 treatment. The highest number of spikes in the first growing season was 237 spikes m^{-2} achieved by the T3 treatment, followed by T2 and Tf with a value of 225 spikes m^{-2}, while the highest number of spikes in the second growing season was 271 and 270 spikes m^{-2} achieved by the Tf and T3 treatments, followed by T2 with a value of 263 spikes m^{-2}.The highest straw yield was achieved by the Tf treatment with values of 3,641 and 3,130 kg fed-1 for the two growing seasons respectively, followed by 3,062 kg fed-1 for the T3 treatment in the first season and 3,130 kg fed-1 for the T2 treatment in the second season.

Table 6. Average yield components and straw yield for different treatments.

Treatment	1,000 grain weight; g		Spike length; cm		Number of spikes m^{-2}		Straw yield; kg fed^{-1}	
	2021/2022	2022/2023	2021/2022	2022/2023	2021/2022	2022/2023	2021/2022	2022/2023
Tf	52.3 b	60.0 b	11.0 c	11.2 b	225	271	3,641 a	3,130
T1	59.5 a	67.5 a	11.7 b	12.3 a	217	233	2,847 b	2,878
T2	72.5 a	68.8 a	12.0 b	12.8 a	225	263	2,796 b	3,130
T3	72.5 a	80.0 a	13.0 a	13.2 a	237	270	3,062 b	3,124
LSD 0.05	19.60 *	14.30 *	0.47 *	1.08 *	37.6 ns	68.9 ns	328.5 *	446 ns

Means followed by the same letter in the same column are not significantly different at the $p \leq 0.05$ level.
*, ns significant and not significantly different at the $p \leq 0.05$ level.
fed. = 4200 m^2
Source: Own calculation based on experimental data.

Water productivity

The averages of water productivity for different treatments are listed in Table 7. The analysis of variance indicated that irrigation treatment had a significant effect on water productivity at a 95% probability level. Raised beds enhanced water productivity compared to flat sowing; many findings fixed that [3, 18]. The T1 treatment achieved the highest water productivity with values of 1.87 and 1.67 kg m^{-3} for the two seasons, respectively, followed by the T3 treatment with values of 1.82 and 1.64 kg m^{-3}. The lowest water productivity was obtained by the Tf treatment with values of 1.17 and 1.03 kg m^{-3} for the two seasons, respectively. The existence of a 20% storage phase decreased water productivity because the water applied increased but was not matched by a corresponding increase in grain yield.

Quality parameters

Wheat grain quality parameters, including hectoliter mass (HLM, kg $100L^{-1}$), Kernel hardness (kg), protein percentage (%), wet and dry gluten percentage (%), and falling number (FN, sec.) for the second season are shown in Table (7). The statistical analysis showed that the irrigation treatments had no significant effect on the quality parameters except for dry gluten. The obtained HLM values ranged from 68.30 to 72.50 kg $100L^{-1}$ without significant differences between treatments. The HLM of normally wheat is between 70 to 85 kg hL^{-1}, but can be altered due to environmental conditions, damage due to insects, water and temperature stress, and nutrient deficiency [26]. The protein concentration was influenced by the availability of water during the growing season. Wheat having high protein content tends to be hard, has strong gluten, and produces good quality bread. The positive correlations between protein content and hardness were reported by [16]. Grains with higher protein content tended to be harder, which results in higher water absorption [14]. The Tf treatment gave the lowest values of HLM and FN, while T1 gave the lowest values of Hardness and wet gluten. The T2 treatment achieved the highest quality parameters.

Table 7. Average quality parameters for different treatments.

Treat	HLM	Hard--ness	Protein	Gluten %		FN
				wet	dry	
Tf	68.3	6.0	13.6	27.4	9.4 b	431
T1	72.5	5.9	13.6	27.3	9.3 b	435
T2	72.5	6.51	13.8	27.8	11.1a	453
T3	71.2	6.3	13.7	27.7	10.7a	446
LSD 0.05	8.1 ns	0.7 ns	1.2 ns	3.2 ns	1.2 *	50.9 ns

Means followed by the same letter in the same column are not significantly different at the $p \leq 0.05$ level.
*, ns significant and not significant at the $p \leq 0.05$.
fed. = 4200 m^2
Source: Own calculation based on experimental data.

CONCLUSIONS

Depending on the results obtained, the bed-furrow irrigation system saved irrigation water and improved the wheat grain yield at the same time. The presence of a storage phase leads to an improvement in water application efficiency and distribution uniformity. The application of the storage phase by 30% increased the wheat grain yield, while the application of the storage phase by 20% increased the water productivity and grain quality parameters. The application of the storage phase is considered a successful irrigation management strategy to enhance bed-furrow irrigation efficiency and raise wheat grain yield and quality parameters.

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