Spectrum of Engineering Sciences
ISSN (e) 3007-3138 (p) 3007-312X Volume 3, Issue 6, 2025

SUSTAINABLE WHEAT PRODUCTION UNDER WATER SCARCITY: EVALUATING IRRIGATION STRESS AND SOWING TECHNIQUES IN PAKISTAN

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DOI: https://doi.org/10.5281/zenodo.15754303

Keywords
Population, Water Productivity, Wheat Yield, Irrigation Methods, Climate Change

Article History
Received on 17 May 2025
Accepted on 17 June 2025
Published on 27 June 2025

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Abstract
Pakistan is facing a water shortage problem due to climate change impacts and an increasing population. The country has already been in the category of water-scarce countries with per capita water availability of less than 1000 m³. Increasing population also demands more food, which can only be secured by increasing the water productivity of staple food crops under limited water availability. However, the water productivity of different crops in Pakistan is low compared to other countries. The study was conducted to investigate different options for enhancing the water productivity of wheat, which is an important grain crop in the country. The specific objective of this study was to evaluate the response of two different irrigation methods and three different irrigation stress levels on the wheat yield and water productivity under semi-arid conditions. Two different irrigation/ sowing methods were traditional flat sowing and furrow-bad planting. For testing different stress levels under the deficit irrigation approach, three Management Allowed Deficit (MAD) levels viz. 50%, 70%, and 90% were evaluated regarding reduction in yield and enhancement in water productivity. The study provided the results regarding optimum irrigation schedules under a water shortage scenario to achieve optimum yields and water productivity at a regional scale.

INTRODUCTION

The current population inclination rate indicates that the world population will become 9.1 billion people in 2050 from the current 6.9 billion, and as a result, the food requirement will increase by 70% globally and by 100% for the developing countries(Gustafsson, Cederberg, Sonesson, & Emanuelsson, 2013). The contribution of the agriculture sector to GDP is 20.9 percent, and it employs 43.5 percent of the total country labor. Also, 62% of the county's rural population directly or indirectly find their livelihood from agriculture(Zhou et al., 2016). Another aspect that is not completely focused in statistics is that agriculture not only provides raw materials for industry producing Pakistan's exports but is also a great consumer of industrial commodities like fertilizer, pesticides, tractors, and agricultural implements. Regardless of agriculture's importance in the above fields, agricultural production, especially in the crop sector, is decreasing over the past three decades(Harris et al., 2009).

Land and water are two vital resources for agriculture, and they are directly linked with world challenges like food insecurity, climate change, and the depletion of natural resources(Jones et al., 2017). As the world population is continuously increasing, the food requirement to feed this increasing population is also increasing, while the available input resources are decreasing day by day due to urbanization and industrialization. Water is an important input for sustainable agriculture and a key source of irrigation in Pakistan is the canal system, feeding from Indus river basin and providing water for the 90 percent of food production. It is estimated that there will be 70 million ton of food shortage by 2025 due to a 32 percent difference between supply and demand of irrigation water in Pakistan(Qureshi, 2011).

The part of irrigation in the development of Pakistan is very important as 80% of the food production of Pakistan is from irrigated lands(Kirby, Tellegen, & Steindl, 2017). But while having a look at the field level, it is visible that the water availability at the watercourse tail is very much different from the water availability at the head(Das, Bae, Wells, & Roy, 2009). This is because of the reason that 40 to 50% water is lost due to malfunctioning of our delivery system. Since the tale users have to face water shortage to meet the crop water requirements resulting in low production(A. Khan, Ahmad, Manzoor, & Khan, 2010).

Surface irrigation techniques are broadly used in all regions of the world. Conversely, these methods have habitually low irrigation efficiency and low distribution uniform mity(Pereira, Da Mata, Figueiredo, de Andrade, & Pereira, 2017). The main problems of surface irrigation methods are deer percolation and high runoff. Consequently, reducing runoff and deep percolation while meeting the irrigation requirement of crops can increase the irrigation performance(Wang et al., 2021). Keeping in view the above-mentioned aim, several management techniques have been developed to diminish losses of water during irrigation events. In the deficit irrigation technique, a smaller application of water improves irrigation performance, reducing deep percolation that may reduce the chemical leaching to the ground water. This method also reduces the runoff losses(Wang et al., 2021).

Climate change impact in Pakistan can be seen in the form of seasonal variation in rainfall, which is increasing in summer and in winter months decreasing in winter months this demands surface water storage during rainy seasons for beneficial use in winter months but Pakistan has very limited storage as compared to other countries(Bushra Jabeen et al., 2013). Per capita surface water storage of America is more than 5000 $m^{3,}$ and China can store 2200 m^3 per capita, but Pakistan stores only 150 m^3. Surface water reservoirs of Colorado can store the 900 days of river flow, India can store the 220 days of river flow, but Pakistan store only the 30 days of river flow (World Bank, 2005). Under the scenario, Rabi crops like wheat are under threat of water shortage, and there is a need to plan suitable strategies for increasing the yield of wheat per drop of water{(Bushra Jabeen et al., 2013).

Another important issue in Pakistan is the increasing population, which antagonistically affects the per capita availability of surface water(Fida, Li, Wang, Alam, & Nsabimana, 2023). In 1951, per capita water availability was 5260 cubic meters (m3) in Pakistan, and it decreased to 1036 m3 in 2012. It may reach to 860 m^3 by 2025, while the threshold value for per capita surface water availability is 1000 m^3 to meet the food and health issues. Pakistan has one of the largest irrigation system in the world but two two-thirds of water. The main reasons of this threatening situation are inadequate storage facilities, depletion of storage capacities, unmanaged potential (hill torrent), low system efficiency, low water productivity, ground water abstraction, etc. (WAPDA, 2014). Water is too important for the crop growth as well as for the satisfactory level of yield production in the agriculture sector. The proper maintenance of water works will minimize the loss of water to ensure better efficiency in return. Water is key in terms of its role in limiting the crop yield(Knox, Nault, Henderson, & Liberzon, 2012). Due to increasing competition among different sectors, it is becoming limited in availability. Rainfall in larger parts of Pakistan is about 240 mm, which ranks it among the arid countries of the world (World Bank, 2006) .

An increasing population also demands more food, which can only be secured by increasing water productivity of staple food crops under limited water availability. Wheat is an important cereal crop and grown all over the world (Fida et al., 2023). Wheat is used as raw material for many food items. It is also very important for Pakistan as contributing 13.7% to agriculture while 3% to GDP(Shahzad, Baig, Rehman, Saeed, & Asim, 2022). During the year 2013, 240 million ha area under wheat cultivation produced 740 million tons of wheat(Heidi, 2013). Wheat is an important staple food in Pakistan too; therefore, this most important crop is sown all over the country from sea level to Himalayas. Wheat contribution to the everyday eating regimen of the normal man is 60 percent, and normal per capita annual utilization is around 125 kg. During 2014-15, 9180 million ha was under wheat cultivation in Pakistan, which produced 25478 thousand tons of wheat at the rate of 2775 kg/ha. The production of wheat decreased to 1.7 percent during 2014-15 as compared to 2013-14(S. Khan, Ullah, Ullah, & Rehman, 2016).

Raised bed planting is an important in which we save approximately 50% water and get high water productivity. Similarly, different stress levels used to get optimal yield of wheat crop(Abdelrasheed et al., 2021). Commonly 4-5 irrigations required for the wheat crop in Punjab. First irrigation applied at crown root initiation stage 15-20 days after sowing and remaining irrigations are applied after the interval of 30-35 days subsequently (Mahmood and Ahmed, 2005). Pakistan irrigation system designed for low cropping intensity which is 75 percent but in the present day cropping intensity reached up to 180 percent. This study was conducted to evaluate the response of two different irrigation methods and three different irrigation levels on the wheat yield and water productivity under semi-arid condition(Tari, 2016).

1. MATERIALS AND METHODS

This section outlines the methods employed for data collection and analysis to achieve the research objectives. It includes descriptions of the experimental site, climatic conditions, soil characteristics, field layout, and management practices.

2.1 Experimental Site

2.1.1 Geographical Location

The study was conducted at the Water Management Research Centre (WMRC), Jhang Road, Faisalabad (31° 25'45'' N, 73° 4'44'' E, elevation 184 m) during the rabi season of 2015-16 on a wheat crop. The region has a semi-arid climate with an average annual rainfall of 350 mm.

2.1.2 Climate

Temperatures range from -2°C in winter to 50°C in summer, with an annual mean of 24°C. The monsoon season delivers most of the rainfall between June and September.

2.1.3 Cropping Pattern

The study area belongs to the rice-wheat and sugarcane agro-ecological zone of Punjab. Major crops include wheat, rice, maize, and sugarcane.

2.1.4 Soil Characteristics

The fertile soil, derived from alluvial deposits of the Himalayas, has a medium texture and homogeneity up to a depth of 4 m. Soil pH ranges between 7 and 7.9 with low organic matter content.

2.2 Field Layout

The experiment was conducted using a randomized complete block design (RCBD) on a 0.77-acre field. There were 18 plots (each 18 ft x 103 ft), and treatments were replicated three times. The plots were divided based on soil moisture-based irrigation scheduling methods.

2.2.1 Treatment Description

- **Irrigation Methods:**
  - M1: Bed Furrow Irrigation
  - M2: Flood/Conventional Irrigation

Irrigation Treatments:

- I1: Irrigation at 50% Available Water (AW), refilled to 100%
- I2: Irrigation at 30% AW, refilled to 80%
- I3: Irrigation at 10% AW, refilled to 60%

2.3 Land Preparation

The field was laser-leveled, and rauni irrigation was applied. Disk plowing, followed by cultivator and planker operations, prepared the soil. Plots were divided into drill and bed sowing methods. The wheat variety "Galaxy" was sown on November 14, 2015, at a seed rate of 35 kg per acre. Fertilizer application included 100 kg of DAP and 25 kg of urea per acre.

Table 2.1: Management activities of field

Management activities	Name
Seed variety	Galaxy
Cultivator	Tine type cultivator
Sowing method	Seed drill and seed bed planter
DAP amount	50 kg/ acre

Table 2.2: Schedule of activities in field

Sr. no	Activities	Year 2015-2016
1	Rouni irrigation	31 October 2015
2	Disk plough	12 November 2015
3	Planking	13 November 2015
4	Sowing	14 November
5	Harvesting	21 April 2016

2.3.2 Water sampling and analysis

Wheat crop experiment was irrigated through skimming well. After running the tube well water samples were collected with a standard procedure. Different parameter like pH, Total soluble salts (TSS), EC, Sodium, Sodium Absorption Ratio (SAR) and Residual Sodium Chloride (RSC) etc were determined and characterize the water quality on their standards.

Table 2.3: Water quality table

Source of water	Skimming well	SAR	0.9
PH	8.2	RSC	1.2
EC	1.47	Remarks	Fit for irrigation
TDS	941		

2.4 Data Collection

Data was collected on soil, meteorological, and agronomic parameters as detailed below.

Soil Data:

- Textural analysis
- Field capacity
- Permanent wilting point
- Soil textural classification
- Infiltration using a double-ring infiltrometer
- Soil moisture monitoring

Meteorological Data:

- Rainfall
- Temperature
- Sunshine hours
- Wind speed
- Mean relative humidity

Agronomic Data:

- Plant density per square meter
- Tiller count per square meter
- Plant height

ISSN (e) 3007-3138 (p) 3007-312X Volume 3, Issue 6, 2025

- Spike length
- Number of spikelets per square meter
- Grains per spike
- 1000-grain weight
- Biological yield
- Grain yield
- Harvest index
- Water productivity

2.4.1 Determination of Soil Parameters

2.4.1.1 Bulk Density:

Measured using the core method (Blake and Hartage, 1986) with a core sampler of radius 3.6 cm and height 5 cm. Oven-dried samples at 105°C were used to calculate soil bulk density as follows:

λ=WdV\lambda = \frac{W_d}(Marengo et al.) λ=VWd

where λ\lambdaλ is bulk density, WdW_dWd is oven-dried soil weight, and VVV is soil volume.

2.4.1.2 Field Capacity:

Field capacity was determined by oven-drying soil samples (0-45 cm depth) at 105°C and calculating volumetric moisture content using:

SWC=Ww−WdWd×AsSWC = \frac{W_w - W_d}{W_d} \times As SWC=WdWw−Wd×As

where SWCSWCSWC is soil water content, WwW_wWw is wet weight, WdW_dWd is dry weight, and AsAsAs is apparent specific gravity.

2.4.1.3 Permanent Wilting Point:

Defined as the moisture level at which plants cannot recover after wilting. Assumed at 15 bars of tension (Thomas et al., 1994).

2.4.1.4 Soil Textural Classification:

Determined using the hydrometer method (Bouyoucos, 1962). Soil was suspended in water, and hydrometer readings were taken at 40 seconds and 2 hours to calculate sand, silt, and clay percentages using Stokes' law. Soil texture was classified using the USDA textural triangle.

2.4.1.5 Infiltration

Infiltration refers to the process of water penetrating the ground surface, measured by the infiltration rate (volume per unit area per time). Stainless steel infiltration rings (diameters: 28/53 cm, 30/55 cm, and 32/57 cm) were used to measure this rate. Rings were driven 10 cm into the soil, and water was added to maintain a 15 cm level. Readings were taken at intervals of 2, 5, 10, 15, 30, and 60 minutes to plot time vs. cumulative infiltration and infiltration rate graphs.

2.4.1.6 Soil Sampling and Analysis

Bulk soil samples from different locations within each treatment were analyzed at the WMRC lab for parameters such as soil texture, bulk density, field capacity, wilting point, electrical conductivity (EC), organic matter percentage, and pH.

2.4.1.7 Irrigation Scheduling

Irrigation was scheduled based on available soil moisture (ASM) depletion. Soil moisture content was determined using the gravimetric method. The irrigation requirement was calculated using:
where FC is field capacity, MC is soil moisture, BD is bulk density, and DRZ is root zone depth.
A cut-throat flume measured water flow, and irrigation time was calculated using the formula:
Soil moisture monitoring graphs highlighted depletion and refilling events.

2.4.1.8 Measurement of Discharge

Discharge measurements were taken using an 8" x 3' cut-throat flume, ensuring proper installation to prevent leakage. Flow conditions (free or submerged) were analyzed, and discharge calculations were made using formulas for free and submerged flows.

2.4.2 Meteorological Data

Effective precipitation was calculated using Smith's (1988) formula. Maximum rainfall occurred on March 19, 2016 (45 mm). Seasonal data for temperature, humidity, sunshine hours, and wind speed were recorded.

2.4.3 Crop Data

Key parameters recorded included:

- Number of plants and tillers per square meter
- Plant height, spike length, and spikelets per spike
- Number of grains per spike and 1000-grain weight

- Biomass yield, grain yield, and biological yield

The harvest index (HI) was calculated as:
Water use efficiency (WUE) was calculated using:
where GY is grain yield, and AIW is applied irrigation water.

1.5 Irrigation Performance Evaluation

2.5.1. WinSRFR Model

WinSRFR, developed by USDA-ARS, was used for hydraulic analysis and simulation. Key functionalities include event analysis, simulation, physical design, and operational analysis.

2.5.2. Event Analysis: Merriam-Keller post-irrigation volume balance was used to estimate infiltration parameters.

2.5.3. Simulation: The model predicted surface flow and infiltration patterns based on field geometry, hydraulic resistance, and boundary conditions. Performance indicators included application efficiency (AE), distribution uniformity (DU), and runoff fractions.

3. RESULTS AND DISCUSSIONS

The experiment was conducted to check the impact of different irrigation levels and sowing methods on wheat crop production and water productivity. This chapter summarizes the results of investigations, and also includes the statistical analysis of data.

3.1 Plant growth parameters

3.1.1 Number of Plants per square meter

Table 3.1 shows the Analysis of Variance (ANOVA) for No. of plants per square meter, while the means for different treatments have been shown in Table 3.2.

Table 3.1: ANOVA for Number of Plants per square meter

Sources	DF	SS	MS	F	P
Block	2	459.11	229.556		
Treatments	5	2554.28	510.856	2.02	.1613
Error	10	2531.56	253.156		
Total	17	554.94			

Table 3.2: Means for Number of plants per square meter

Sr No	Treatments	Description	Means
1	T_1	M_1I_1	128.67 AB
2	T_2	M_2I_1	111.67 B
3	T_3	M_1I_2	143.67 A
4	T_4	M_2I_2	124.33 AB
5	T_5	M_1I_3	146 A
6	T_6	M_1I_3	138 AB

ANOVA shows that the results for this parameter are not significant. This is because of that at the time of sowing same moisture condition and same seed rate applied in all the treatments. It is cleared from the means that T_3 and T_5 are significantly high and T_2 is significantly low(Ashraf & Foolad, 2005). T_1, T_4 and T_6 are statistically at par. For the irrigation level I_1, numbers of plants per square meter were 15.22% high for bed planting as compared to flat drill sowing. Under irrigation level I_2, numbers of plants per square meter for the bed planting were 15.55% high as compared to the flat drill sowing. Number of plants per square meter for the I_3, was 6.79% high for bed planting corresponding to flat drill sowing(PRAKASH).

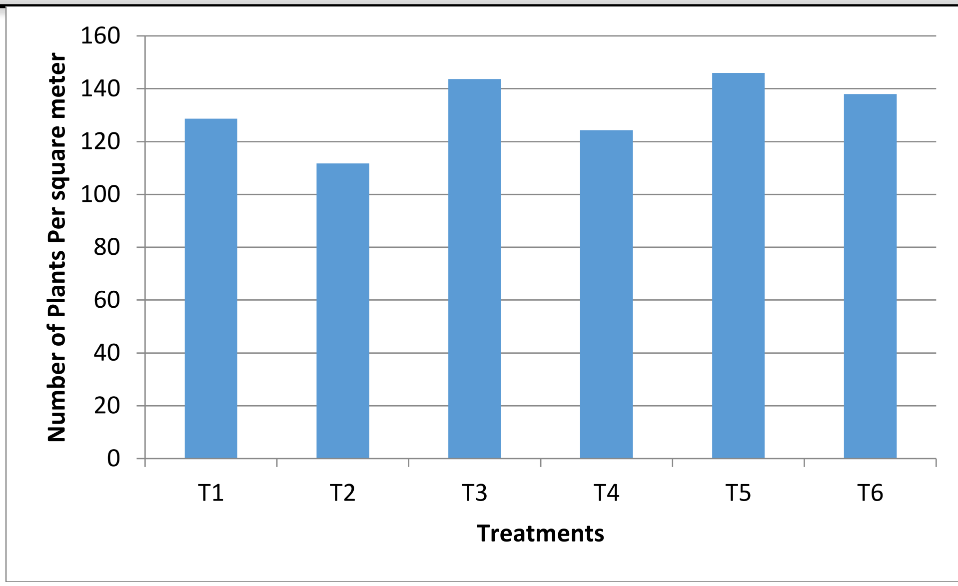

Fig. 3.1: Means of number of plant per square meter for different treatments

3.1.2. Number of tillers per square meter

Table 3.3 shows the Analysis of Variance (ANOVA) for No. of tillers per square meter, while the means for different treatments have been shown in Table 3.4.

Table 3.3: ANOVA for Number of tillers per square meter

Sources	DF	SS	MS	F	P
Block	2	885.4	442.72		
Treatments	5	8375.1	1675.02	2.83	.0760
Error	10	5921.2	592.12		
Total	17	15181.8			

Table 3.4: Means for number of tillers per square meter

Sr No	Treatments	Description	Means
1	T_1	M_1I_1	233.00 AB
2	T_2	M_2I_1	224.67 ABC
3	T_3	M_1I_2	247.00 A
4	T_4	M_2I_2	219.00 ABC
5	T_5	M_1I_3	195.00 BC
6	T_6	M_1I_3	184.00 C

Statistical result for the tiller data was not significant. Highest no of tillers was under T_3 i.e., 247 (per square meter), and minimum number of tillers under T_6 i.e., 184 (per square meter). The remaining treatments were statistically at par. Results indicated that in all three irrigation treatments number of tillers in bed sowing is more as compared to the flat drill planting. For the irrigation level I_3, no. of tillers was 6% high for the bed planting than flat drill sowing. Number of tillers for irrigation level I_2, was 12.78 % high under bed planting than flat drill sowing. For the irrigation level I_1, numbers of tillers were approximately same(KUMAR, 2024).

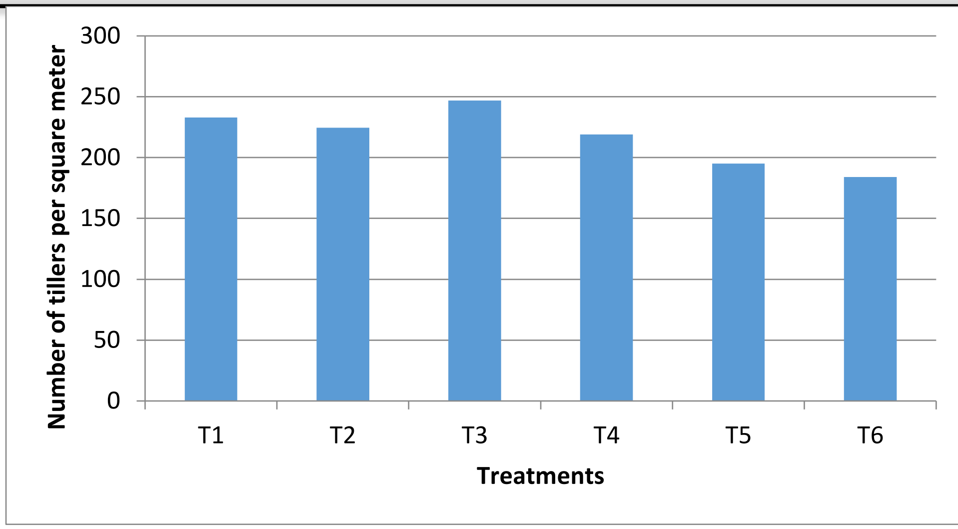

Fig. 3.2: Means of number of tillers per square meter for different treatments

3.1.3. Plant height

3.1.4. Table 3.5 shows the Analysis of Variance (ANOVA) for plant height, while the means for different treatments have been shown in Table 3.6.

Table 3.5: ANOVA for plant height

Sources	DF	SS	MS	F	P
Block	2	11.738	5.869		
Treatments	5	786.811	157.362	13.45	.0004
Error	10	116.982	11.698		
Total	17	915.531			

Table 3.6: Means of plant height

Sr No	Treatments	Description	Means
1	T_1	M_1I_1	89.067 B
2	T_2	M_2I_1	94.467 AB
3	T_3	M_1I_2	93.067 AB
4	T_4	M_2I_2	95.533 A
5	T_5	M_1I_3	77.667 C
6	T_6	M_1I_3	82.267 C

Statistical analysis in table 3.6 shows the significant results of different sowing and irrigation methods. It means there is difference between plant heights under different sowing and irrigation method(Maqsood, Hussain, Tayyab, & Ibrahim, 2006). Plant height of T_4 is significantly high (95.533 cm) and plant height for the T_5 is significantly low (77.667 cm). Results of T_2 and T_3 are statistically at par. Highest plant height is obtained in the flat sowing under I_2, and the lowest under the bed sowing under I_3,. It can be concluded that high water stress in I_3 highly affected the plant height in both bed sowing and flat sowing. Results indicated that the plant height for the irrigation level I_1, 6.06% more for flat sowing as compared to the bed sowing. Plant height for irrigation level I_3, was 5.92% high for flat sowing than bed planting. Under irrigation level I_2, plant height was 2.64% high for flat sowing(Irfan & Ahmad, 2014).

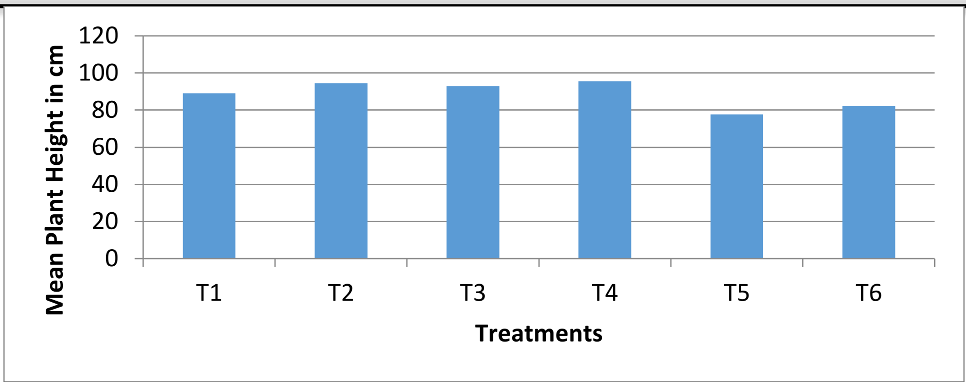

Fig. 3.3: Means of plant height for different treatments

3.1.5. Spike length

Table 3.7 shows the Analysis of Variance (ANOVA) for spike length, while the means for different treatments have been shown in Table 3.8

Table 3.7: ANOVA for spike length

Sources	DF	SS	MS	F	P
Block	2	0.2575	0.12875		
Treatments	5	7.3763	1.47525	5.09	.0140
Error	10	2.8975	28975		
Total	17	10.5313			

Table 3.8: Means of spike length

Sr No	Treatments	Description	Means
1	T_1	M_1I_1	9.483 BC
2	T_2	M_2I_1	10.433 AB
3	T_3	M_1I_2	10.167 AB
4	T_4	M_2I_2	10.467 A
5	T_5	M_1I_3	8.633 C
6	T_6	M_1I_3	9.667 AB

Statistical analysis for the spike length is significant. Its means that the all treatments showed the different response to different sowing and irrigation methods. Highest spike length under T_4 i.e., 10.467 cm, and lowest spike length was under T_5 i.e., 8.633 cm. Results indicated that the spike length for irrigation treatments I_1, I_2, and I_3 were 10 %, 2.95 % and 11.97 % high respectively for flat sowing than bed planting(Rady, Semida, Howladar, & Abd El-Mageed, 2021).

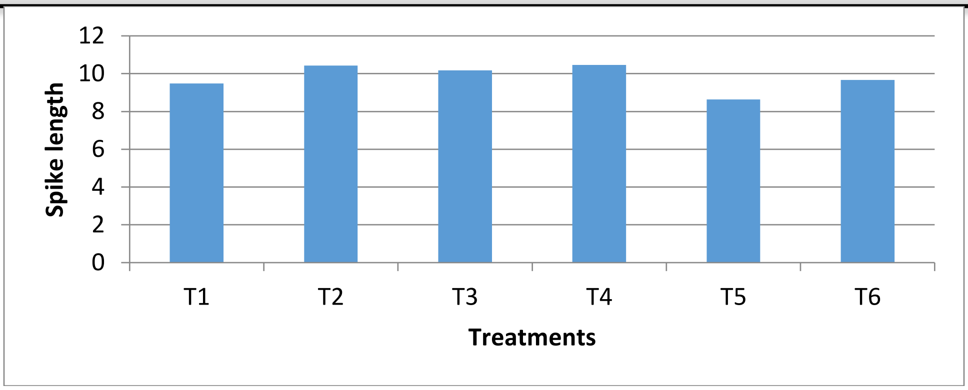

Fig. 3.4: Means of the Spike length for different treatment

3.1.6. No. of spikelets per spike

Table 3.9 shows the Analysis of Variance (ANOVA) for No. of spikelets per spike, while the means for different treatments have been shown in Table 3.10.

Table 3.9: ANOVA for number of spikelets per spike

Sources	DF	SS	MS	F	P
Block	2	.6100	0.30500		
Treatments	5	36.3971	7.27833	9.21	.0017
Error	10	7.9033	0.79033		
Total	17	44.9050			

Table 3.10: Means of number of spikelets per spike

Sr No	Treatments	Description	Means
1	T_1	M_1I_1	16.500 AB
2	T_2	M_2I_1	17.200 A
3	T_3	M_1I_2	16.500 AB
4	T_4	M_2I_2	17.400 A
5	T_5	M_1I_3	13.167 C
6	T_6	M_1I_3	15.533 B

Results of statistical analysis for the number of spikelts per spike were significant. It showed that for all the treatments (sowing and irrigation) number of spikelets per spike was different. The response of treatment under flat sowing and I_2, was significantly high, and the response of treatment under bed sowing and I_3 irrigation level was not significant(Fahong, Xuqing, & Sayre, 2004).

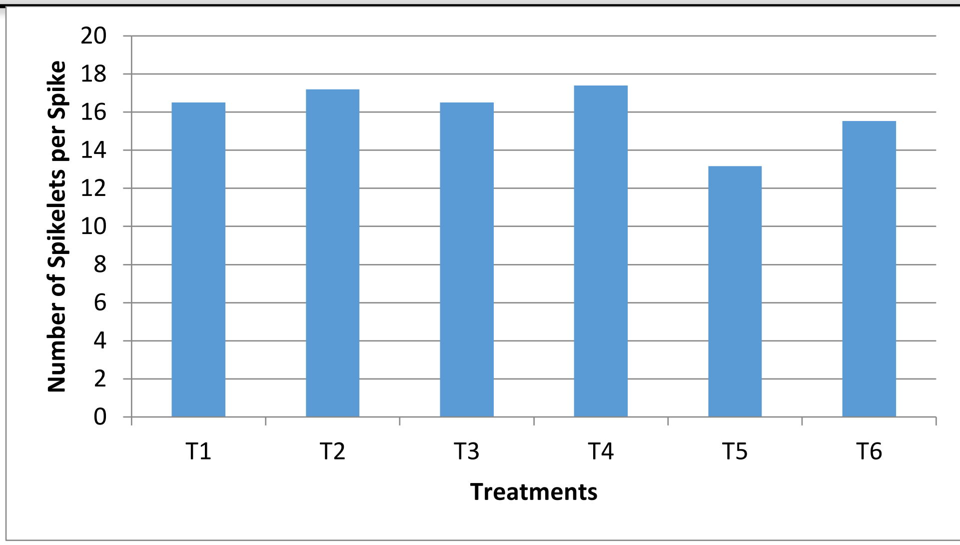

Fig. 3.5: Mean of number spikelets per spike for different treatments

3.1.7. Number of grains per spike

Table 3.11 shows the Analysis of Variance (ANOVA) for No. of grains per spike, while the means for different treatments have been shown in Table 3.12.

Table 3.11: ANOVA for number of grain per spike

Sources	DF	SS	MS	F	P
Block	2	12.848	6.4239		
Treatments	5	175.769	35.1539	3.92	0.0314
Error	10	89.619	8.9619		
Total	17	278.236			

Table 3.12: Means for the number of grains per spike

Sr No	Treatments	Description	Means
1	T_1	M_1I_1	48.633 A
2	T_2	M_2I_1	52.000 A
3	T_3	M_1I_2	48.733 A
4	T_4	M_2I_2	50.733 A
5	T_5	M_1I_3	42.300 B
6	T_6	M_1I_3	46.633 AB

The results of no of grains per spike were statistically significant. The highest no of grain per spike was in T_2 that was 6.92 % more than T_1 and lowest no of grains in the T_5 which was 10.24 % less than T_6. In the flat sowing for all treatments number of grains per spike was high as compared to the bed sowing but the grain yield was high under bed sowing. Reason of this was that the grain quality of bed sowing was high as compared to the flat sowing(Majeed et al., 2015).

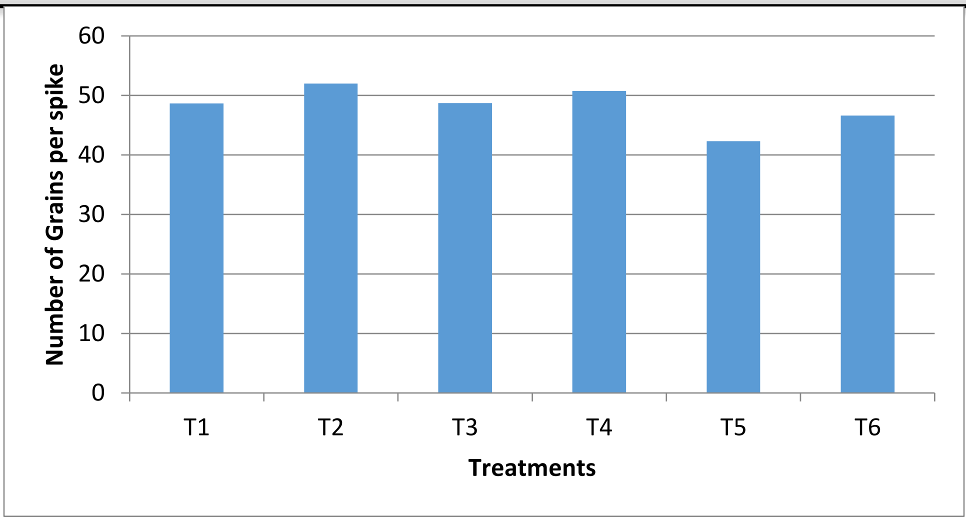

Fig. 3.6: Means of number of grains per spike for different treatments

3.1.8. 1000 grain weight

Table 3.13 shows the Analysis of Variance (ANOVA) for 1000 grain weight, while the means for different treatments have been shown in Table 3.14.

Table 3.13: ANOVA for 1000 grain weight

Sources	DF	SS	MS	F	P
Block	2	8.33	4.1667		
Treatments	5	122.667	24.5333	27.26	0.0000
Error	10	9.000	0.9000		
Total	17	140.000			

Table 3.14: Means of 1000 grain weight

Sr No	Treatments	Description	Means
1	T_1	M_1I_1	48.667 A
2	T_2	M_2I_1	46.667 B
3	T_3	M_1I_2	46.667 B
4	T_4	M_2I_2	44.333C
5	T_5	M_1I_3	41.00 D
6	T_6	M_1I_3	42.667 CD

1000 grain weight is the indicator of wheat quality. Statistical analysis results for the 1000 grain weight were significant. The average 1000 grain weight of T_1 was significantly high i.e., 48.667 g which was 4.28 % high than T_2 flat sowing, and average 1000 grain weight of T_5 was significantly low i.e., 41.00 g than T_6 that is 4.06 % . On the other hand the grain weight of T_2 and T_3 were also significant, not highly differ from T_1(Sokoto, Abubakar, & Dikko, 2012). Under irrigation treatment I_2 average 1000 grain yield was 5.26 % less for flat sowing as compared to bed planting. Results indicated that under irrigation treatment I_1 the grain quality was good as compared to the other two treatments I_2 and I_3. It was concluded that the grain quality of bed sowing under I_1 and I_2 was high than the flat drill sowing but for I_3 the results were in contrast. High water stress treatment showed more grain reduction in bed sowing than in flat sowing(Majeed et al., 2015).

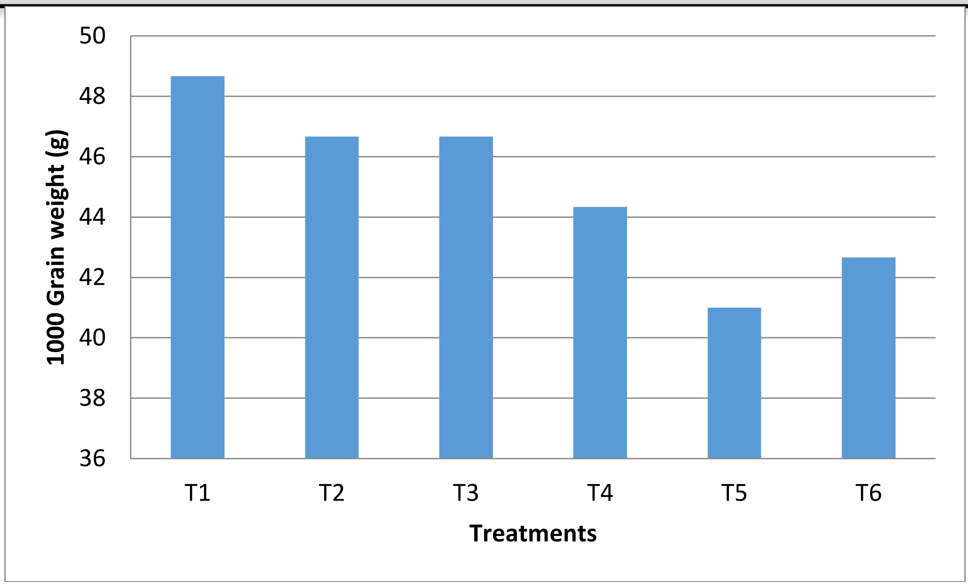

Fig. 3.7: Means of 1000 grain weight for different treatments

3.1.9. Biological yield

Table 3.15 shows the Analysis of Variance (ANOVA) for dry matter weight, while the means for different treatments have been shown in Table 3.16.

Table 3.15: ANOVA for dry matter weight

Sources	DF	SS	MS	F	P
Block	2	40887	20443.6		
Treatments	5	233158	46631.7	1.41	.1832
Error	10	331433	33143.3		
Total	17	605478			

Table 3.16: Means of dry matter weight

Sr No	Treatments	Description	Means
1	T_1	M_1I_1	952.00 A
2	T_2	M_2I_1	983.33 A
3	T_3	M_1I_2	994.00 A
4	T_4	M_2I_2	980.67 A
5	T_5	M_1I_3	700.67 A
6	T_6	M_1I_3	786.00 A

Statistical results for the dry matter weight were not significant. Highest dry matter weight was obtained under flat sowing for irrigation level I_2, and lowest dry matter weight was obtained under bed sowing for irrigation level I_3. Among the bed sowing high dry matter weight was obtained under T_3 (I_2) followed by T_1 and T_5 respectively. Among the flat sowing high dry matter weight was obtained for T_2 followed by T_4 and T_6 respectively. The average dry matter weight under I_1 was 983.33 kg/m^3 for the flat sowing (T_2) which was 3.29% more than bed planting. Under irrigation treatment I_2, dry matter was 1.35 % more for the bed sowing. Average dry matter weight for the flat sowing under irrigation treatment I_3 was 786 kg/m^3 which was significantly high than bed planting i.e., 12.17 %. This indicated that the dry matter weights were directly related to the amount of water applied to the crop during the whole growing season(Zhang, Chen, Sun, Pei, & Wang, 2008).

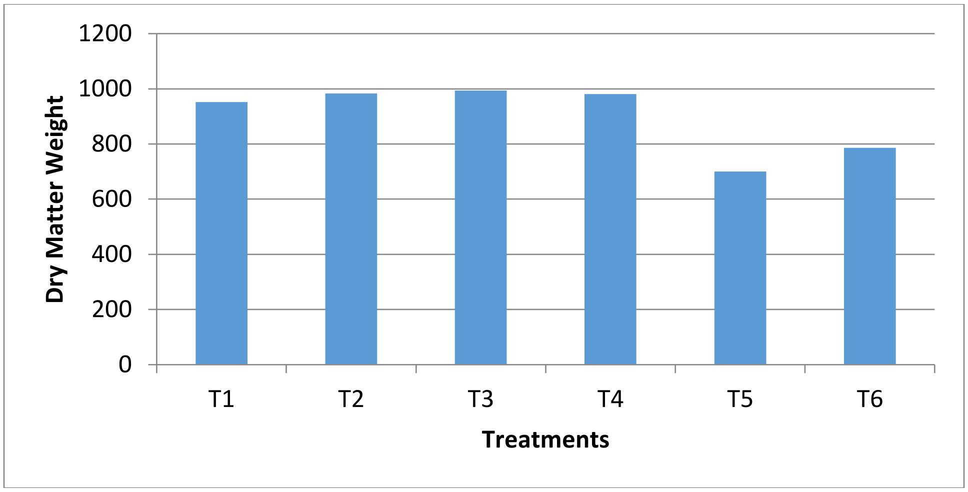

Fig. 3.8: Means of dry matter weight for different treatments

3.1.10. Grain yield

Table 3.17 shows the Analysis of Variance (ANOVA) for grain yield, while the means for different treatments have been shown in Table 3.18.

Table 3.17: ANOVA for grain yield

Sources	DF	SS	MS	F	P
Block	2	2364.2	1182.12		
Treatments	5	48930.6	9786.12	3.09	0.0607
Error	10	31659.3	3165.93		
Total	17	82954.1			

Table 4.18: Means for grain yield

Sr No	Treatments	Description	Means
1	T_1	M_1I_1	4055.0 AB
2	T_2	M_2I_1	4140.00 A
3	T_3	M_1I_2	3840.0 AB
4	T_4	M_2I_2	3700.0 ABC
5	T_5	M_1I_3	2720.00 C
6	T_6	M_1I_3	3060.0BC

Results of the statistical analysis were not significant. The highest grain yield was obtained under flat sowing for irrigation level I_1, i.e., 4140 kg/ha and lowest grain yield obtained under bed sowing for irrigation level I_3 i.e., 2720 kg/ha. The treatment T_2 followed by the T_1, T_3, T_4, T_6 and T_5 respectively. For the irrigation level I_2, the bed sowing resulted in high grain yield than flat sowing but for the other two irrigation levels I_1, and 1_3, the results were vices versa. However, the grain yields of T_1 and T_2 were statistically at par. Yields of the T_3 and T_4 were statistically same, i.e., 3.78 % more in bed sowing as compared to flat sowing, but for T_5 and T_6 the response was statistically different from each other, which was 12.5 % more in flat sowing than in bed planting(Wang et al., 2021).

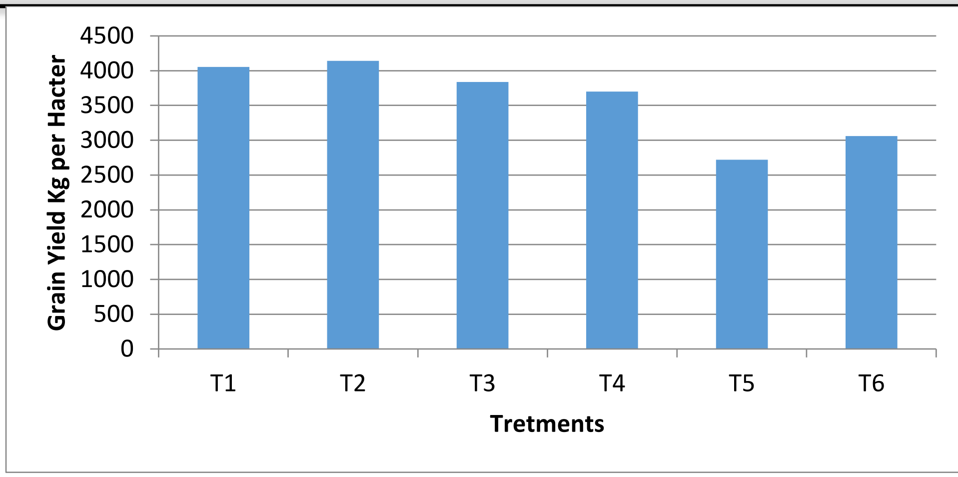

Fig. 3.9: Means of grain yield for different treatments

3.1.11. Harvesting index

Table 3.19 shows the Analysis of Variance (ANOVA) for harvesting index, while the means for different treatments have been shown in Table 3.20.

Table 3.19: ANOVA for harvesting index

Sources	DF	SS	MS	F	P
Block	2	27.869	13.9479		
Treatments	5	63.871	12.774	1.23	0.3621
Error	10	103.485	10.3485		
Total	17	195.252			

Table 3.20: Means for harvesting index

Sr No	Treatments	Description	Means
1	T_1	M_1I_1	43.080 A
2	T_2	M_2I_1	42.287 A
3	T_3	M_1I_2	38.647 A
4	T_4	M_2I_2	38.597 A
5	T_5	M_1I_3	38.733 A
6	T_6	M_1I_3	38.913 A

Highest harvesting index was obtained under the T_1 and lowest under T_3. All the results were statistically at par. Harvesting index was the ratio of grain yield to the biological yield. For the first two irrigation treatments I_1, and I_2 harvesting index was slightly more for bed planting as compared to the flat sowing i.e., 1.87 % and 0.12 % respectively. On the other hand in irrigation treatment I_3, harvesting index was slightly high for the flat sowing as compared to the bed sowing i.e., 0.46 %(Soltani, Galeshi, Attarbashi, & Taheri, 2004).

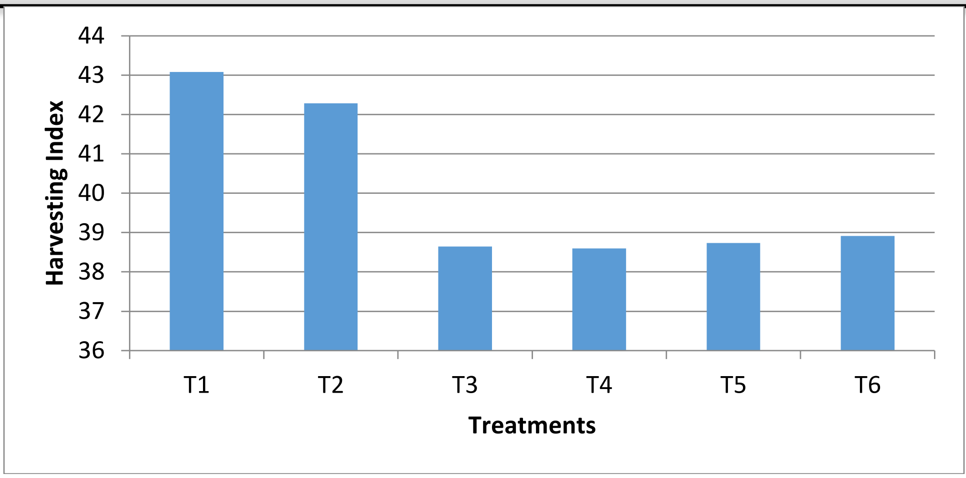

Fig. 3.10: Means of harvesting index for different treatments

3.1.12. Water productivity

Table 3.21 shows the Analysis of Variance (ANOVA) for water productivity, while the means for different treatments have been shown in Table 3.22.

Table 3.21: ANOVA for water productivity

Sources	DF	SS	MS	F	P
Block	2	2364.2	1182.12		
Treatments	5	48930.6	9786.12	3.09	0.0607
Error	10	31659.3	316593		
Total	17	82954.1			

Sr No	Treatments	Description	Grain yield (kg/ha)	Water applied (m^3/ha)	Means
1	T_1	M_1I_1	4055	1978.9	2.01507 A
2	T_2	M_2I_1	4140	2469.1	1.6800 BC
3	T_3	M_1I_2	3840	1691.7	2.2713 A
4	T_4	M_2I_2	3700	2050.7	1.8053 ABC
5	T_5	M_1I_3	2720	1691.3	1.6107 BC
6	T_6	M_1I_3	3060	2048.7	1.4940 C

Table 3.22: Means of Water productivity

Results indicated that the highest water productivity obtained under bed sowing 'T_3' i.e., 2.2713 kg/m^3 which was 25.8% high than the flat sowing. Lowest water productivity obtained under treatment T_6 i.e., 1.4940 kg/m^3. The average water productivity for treatment 'T_1' was 2.01507 kg/m^3 which was 19.94 % more than T_2 (flat sowing). Under irrigation treatment I_3, water productivity of bed planting was 7.81% more than flat sowing. As compared the bed and flat sowing the water productivity of bed sowing was high. Highest water productivity obtained under T_3, which is under mild water stress(Zhao et al., 2020). It was observed from the results that high water stress in I_3 under bed sowing adversely affected the water productivity. In the irrigation treatments I_2 and $I_{3,}$ equal amount out of water was applied but the time of irrigation was changed from each other which is the main factor of decrease in water productivity of T_5 and T(Li, Du, Sun, & Cao, 2019)6.

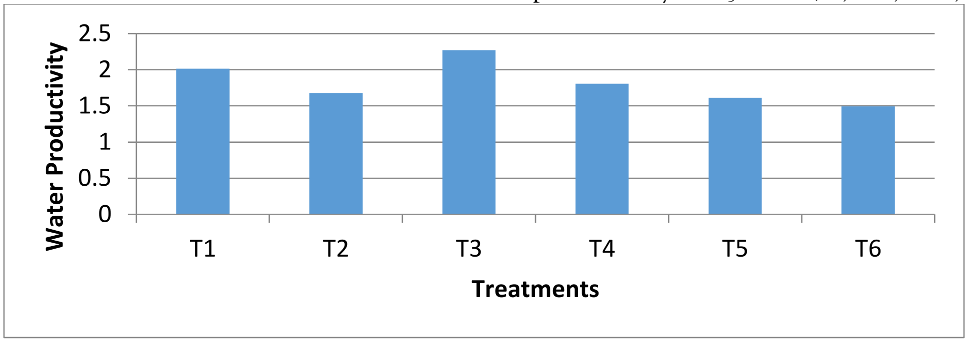

Fig. 3.11: Means of water productivity for different treatments

3.2. Irrigation evaluation by WinSRFR model

3.2.1 Calibration of model

Calibration of model was done manually. During rouni irrigation advance and recession time was noted and then the event analysis world was run to find value of 'a' and 'K'. Event analysis required the data about the field geometry, advance time, recession time, cutoff time and value for kostiakov 'a' which estimates the value of K. All the parameters were recorded in the field and model was run for different values of 'a', i.e., 0.4, 0.5, 0.6, 0.7, 0.8, 0.9 and 1.0. For each value of 'a', cumulative infiltration curve was obtained. The cumulative infiltration curves were compared with the one developed based on the field observed values using double ring infiltrometer to select the value of 'a' which gives best match of curves. Figure 3.12 shows the comparison of different curves, indicating that observed curve was closed to the simulated curve for 'a'= 0.7. This value of 'a', was used as an input for the simulation of all irrigation events(Dechmi, Playan, Faci, Tejero, & Bercero, 2003).

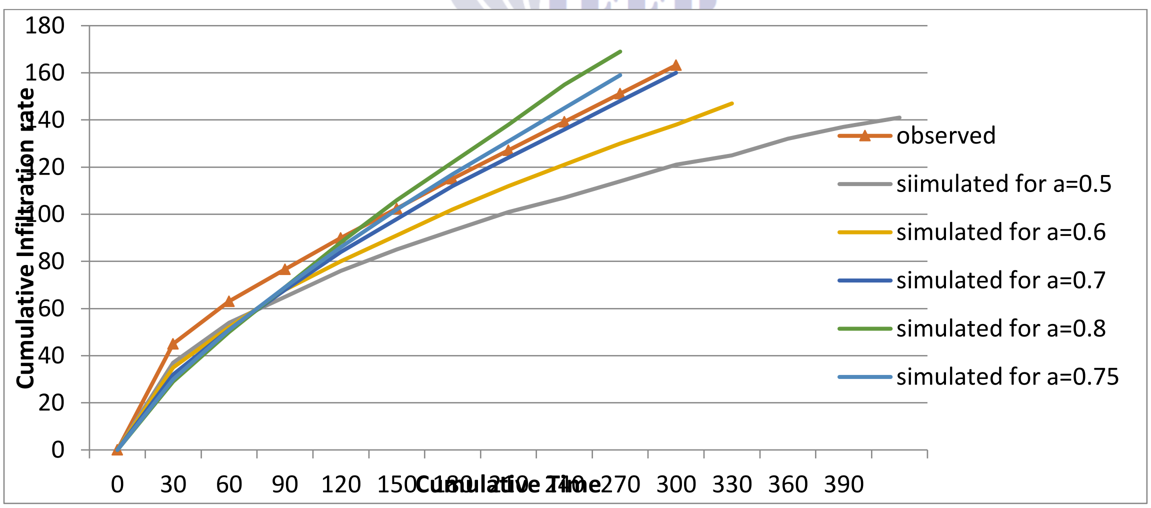

Fig. 3.12: Observed and simulated cumulated infiltration curves for different values of 'a'

3.2.2 Simulation for Different Irrigation Events

3.2.2.1. First irrigation for treatment I_1

Figure 3.13 shows the hydraulic summary of basin irrigation and Figure 3.14 shows the hydraulic summary of bed furrow irrigation for first irrigation event under I_1. A detailed comparison of the different parameters for the two methods is shown in figure 3.14. The hydraulic summary for flood irrigation shows that the advance time for 100 feet 100-foot-long basin was 0.14 hour. The recession time at the start of the field was 0.65 hours and for the last point, the recession time was 1 hour. The irrigation depth required for flood irrigation was 21 mm but the applied depth was 44 mm. Infiltration at

ISSN (e) 3007-3138 (p) 3007-312X Volume 3, Issue 6, 2025

the start of the field was 38 mm and at the end of the field depth was 48 mm. Advance time for the bed furrow was 0.08 hour and recession time was 0.55 hour. The depth required for the bed furrow was also 21 mm but the applied depth was 31 mm which was less than the flood irrigation(Abdallah, Alzoheiry, & Burkey, 2018). Irrigation application efficiency was estimated by the model as 67% and 48% for bed-furrow and border methods, respectively. Distribution uniformity for bed was 98.36% and for the flat was 79%. Adequacy for flood irrigation was high as compared to the bed furrow irrigation i.e., 1.63 and 1.46 respectively. This is because adequacy is a parameter to check whether there is any deficiency of water application or not in a method. The values of more than one for both methods indicate that field was properly irrigated in both methods with heavy irrigation in flat as compared to the bed-furrow method. However, this also resulted in water losses as has already been mentioned above by the values of low application efficiency in case of flat method(Singh, Kundu, & Bandyopadhyay, 2010)

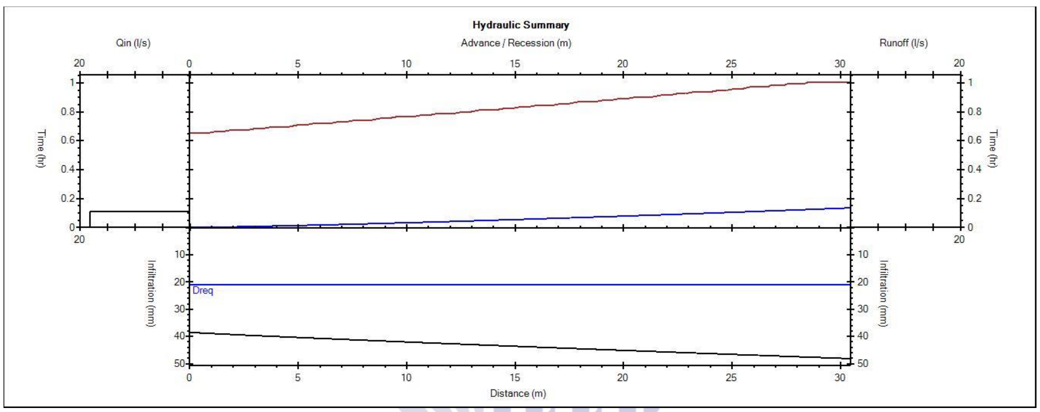

Fig. 3.13: Hydraulic summery of 1st irrigation for treatment I_1 under flat sowing

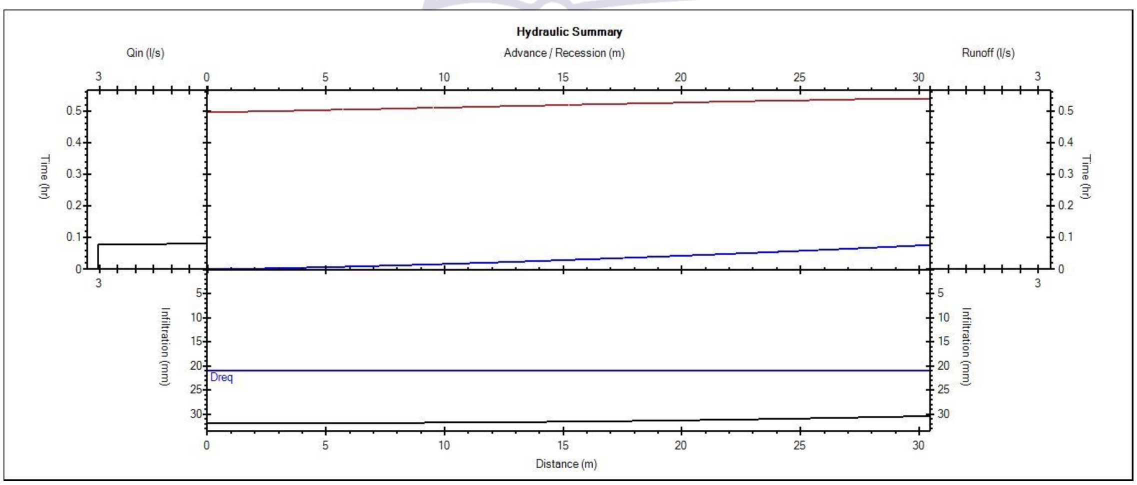

Fig. 3.14: Hydraulic summery of 1st irrigation for treatment I_1 under bed sowing

3.2.2.2. Second irrigation for treatment I_1

Figure 3.15 represents the hydraulic summary of bed furrow irrigation. The detailed comparison of the different parameters for two methods. In the second irrigation, the advance time for basin and bed furrow irrigation was 0.12 and 0.08 hr respectively(Berkout, Yasmeen, Maqsood, & Kalwij, 1997). Recession time at the start of the basin was 0.62 hr and at the end 1.0 hr. In bed furrow irrigation, the recession time at the start was 0.5 hr and at the end point of field the time was 0.54 hr. In the border irrigation 22 mm depth of irrigation required but applied depth was

47 mm. On the other hand for the furrow irrigation required depth was 20 mm and applied depth was 30 mm. in the basin irrigation infiltration depth at the start and end of the field was 39 and 48 mm respectively. Infiltration depth at the start and end point of bed furrow irrigation was 32 and 30.5 mm respectively. Less difference in infiltration at the start and the end of field in bed furrow irrigation indicates that there is higher distribution uniformity in bed furrow irrigation system than basin irrigation. Application efficiency for border and furrow irrigation was calculated as 47% and 66 % respectively. Distribution uniformity for the border irrigation was 93% and for the furrow irrigation was 96%(Soroush, Mostafazadeh-Fard, Mousavi, & Abbasi, 2012).

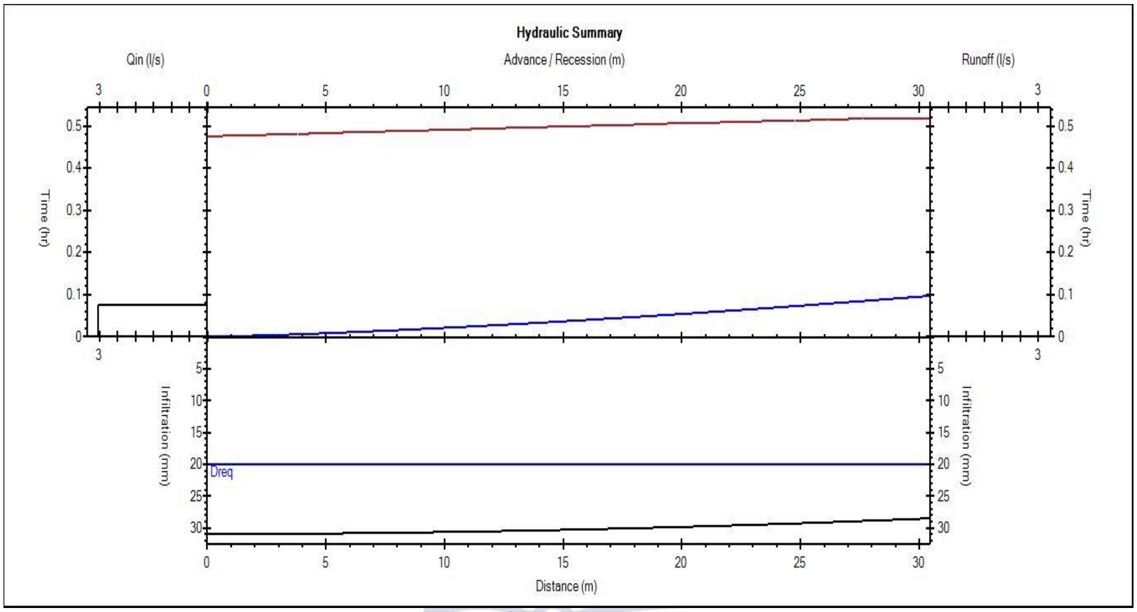

Fig. 3.15: Hydraulic summary of 2nd irrigation for treatment I_1 under bed sowing.

3.2.2.4. Third irrigation for treatment I_1.

Figure 3.16 indicates the hydraulic summary of 3rd basin irrigation of I_1, and figure 4.20 indicates the hydraulic summary of the furrow irrigation(Kurre, 2016). The detailed comparison of the different parameters for two methods is shown in figure 3.17. In the 3rd irrigation, 31mm depth of irrigation was required for the basin and 29 mm for the furrow irrigation. However, the applied depth for basin irrigation was 66 mm and for the furrow irrigation, the applied depth was 44 mm. The advance time for the basin irrigation was 0.20 hr and for the furrow irrigation, the advance time was 0.86 hr. The time required for the Recession at the start point of the basin was 1.24 hr and at the end point time was 1.7 hr. Infiltration was low at the start of the basin that was 62 mm and at the end infiltration was high i.e., 67 mm. In bed planting at the start the infiltration was high that is 46 mm as compared to the end that is 43 mm. Distribution uniformity for the basin and furrow was 93% and 96 % respectively. Application efficiency for the furrow was 66% and for the basin were 47%. Adequacy for the basin irrigation was high i.e., 2.01, and for the furrow irrigation was 1.47(Setu, Legese, Teklie, & Gebeyhu, 2023).

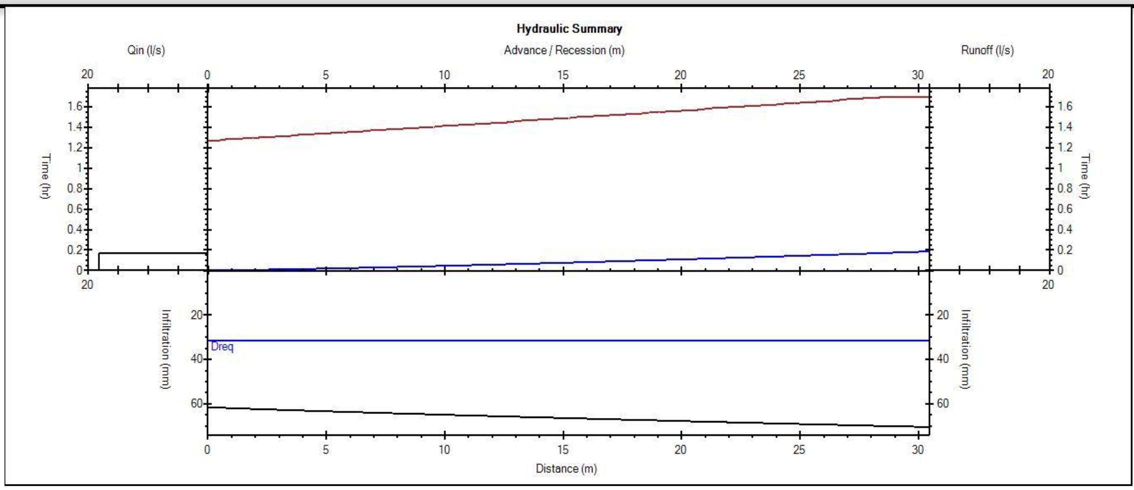

Fig. 3.16: Hydraulic summary of 3rd irrigation for treatment I_1 under flat sowing

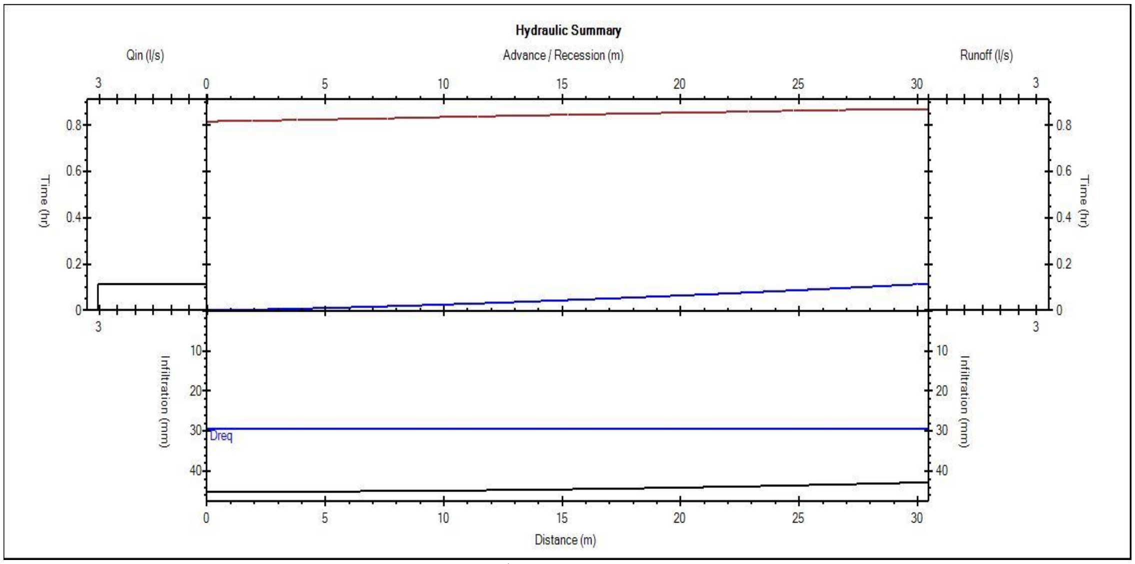

Fig. 3.17: Hydraulic summery of 3rd irrigation for treatment I_1 under bed sowing.

REFERENCES

Abdallah, A., Alzoheiry, A., & Burkey, K. (2018). Comparison of flooded and furrow-irrigated transplanted rice (Oryza sativa L.): Farm-level perspectives. *Journal of irrigation and drainage engineering, 144*(9), 04018022.

Abdelrasheed, K. G., Mazrou, Y., Omara, A. E.-D., Osman, H. S., Nehela, Y., Hafez, E. M., . . . Gowayed, S. M. (2021). Soil amendment using biochar and application of K-humate enhance the growth, productivity, and nutritional value of onion (Allium cepa L.) under deficit irrigation conditions. *Plants, 10*(12), 2598.

Ashraf, M., & Foolad, M. (2005). Pre-sowing seed treatment—A shotgun approach to improve germination, plant growth, and crop yield under saline and non-saline conditions. *Advances in agronomy, 88*, 223-271.

Berkout, N., Yasmeen, F., Maqsood, R., & Kalwij, I. (1997). *Farmers' use of basin, furrow and bed-and-furrow irrigation systems and the possibilities for traditional farmers to adopt the bed-and furrow irrigation method*: IWMI.

Bushra Jabeen, B. J., Naheed Riaz, N. R., Muhammad Saleem, M. S., Naveed, M., Muhammad Ashraf, M. A., Umber Alam, U. A., . . . Abdul Jabbar, A. J. (2013). Isolation of natural compounds from Phlomis stewartii showing α-glucosidase inhibitory activity.

Das, T., Bae, Y. H., Wells, A., & Roy, P. (2009). Profilin-1 overexpression upregulates PTEN and suppresses AKT activation in breast cancer cells. *Journal of cellular physiology, 218*(2), 436-443.

Dechmi, F., Playan, E., Faci, J., Tejero, M., & Bercero, A. (2003). Analysis of an irrigation district in northeastern Spain: II. Irrigation evaluation, simulation and scheduling. *Agricultural water management, 61*(2), 93-109.

Fahong, W., Xuqing, W., & Sayre, K. (2004). Comparison of conventional, flood irrigated, flat planting with furrow irrigated, raised bed planting for winter wheat in China. *Field Crops Research, 87*(1), 35-42.

Fida, M., Li, P., Wang, Y., Alam, S. K., & Nsabimana, A. (2023). Water contamination and human health risks in Pakistan: a review. *Exposure and Health, 15*(3), 619-639.

Gustafsson, J., Cederberg, C., Sonesson, U., & Emanuelsson, A. (2013). The methodology of the FAO study: Global Food Losses and Food Waste-extent, causes and prevention"-FAO, 2011. In: SIK Institutet för livsmedel och bioteknik.

Harris, W. S., Mozaffarian, D., Rimm, E., Kris-Etherton, P., Rudel, L. L., Appel, L. J., . . . Sacks, F. (2009). Omega-6 fatty acids and risk for cardiovascular disease: a science advisory from the American Heart Association Nutrition Subcommittee of the Council on Nutrition, Physical Activity, and Metabolism; Council on Cardiovascular Nursing; and Council on Epidemiology and Prevention. *Circulation, 119*(6), 902-907.

Heidi, K. (2013). *Die Entwicklung der Herrschaft der Athener im Ersten Delisch-Attischen Seebund: Von der Gr ndung bis zur Verlegung der Bundeskasse nach Athen (478/77 v. Chr. bis 454 v. Chr.)*: Diplomica Verlag.

Irfan, M., & Ahmad, R. (2014). EFFECT OF SOWING METHODS AND DIFFERENT IRRIGATION REGIMES ON COTTON GROWTH AND YIELD. *Pakistan Journal of Agricultural Sciences, 51*(4).

Jones, M. L., McLaughlin, M. A., Lam, M. T., Cordes, J. M., Levin, L., Chatterjee, S., . . . Dolch, T. (2017). The NANOGrav nine-year data set: measurement and analysis of variations in dispersion measures. *The Astrophysical Journal, 841*(2), 125.

Khan, A., Ahmad, A., Manzoor, N., & Khan, L. A. (2010). Antifungal activities of Ocimum sanctum essential oil and its lead molecules. *Natural Product Communications, 5*(2), 1934578X1000500235.

Khan, S., Ullah, A., Ullah, K., & Rehman, N.-u. (2016). Insight into hydrogels. *Designed Monomers and Polymers, 19*(5), 456-478.

Kirby, J. N., Tellegen, C. L., & Steindl, S. R. (2017). A meta-analysis of compassion-based interventions: Current state of knowledge and future directions. *Behavior therapy, 48*(6), 778-792.

Knox, D., Nault, T., Henderson, C., & Liberzon, I. (2012). Glucocorticoid receptors and extinction retention deficits in the single prolonged stress model. *Neuroscience, 223*, 163-173.

KUMAR, S. (2024). POWER TILLER OPERATED STRIP-TILL MULTI-CROP PLANTER FOR CONSERVATION AGRICULTURE.

Kurre, R. D. (2016). *Water productivity, hydraulics and economics of furrow irrigated raised bed system with variable furrow sections for wheat crop.* Indira Gandhi Krishi Vishwavidyalaya, Raipur,

Li, D., Du, T., Sun, Q., & Cao, Y. (2019). The key driving factors of irrigation water productivity based on soil spatio-temporal characteristics. *Agricultural water management, 216*, 351-360.

Majeed, A., Muhmood, A., Niaz, A., Javid, S., Ahmad, Z. A., Shah, S. S. H., & Shah, A. H. (2015). Bed planting of wheat (Triticum aestivum L.) improves nitrogen use efficiency and grain yield compared to flat planting. *The crop journal, 3*(2), 118-124.

Maqsood, M., Hussain, T., Tayyab, M., & Ibrahim, M. (2006). Effect of different irrigation levels on the yield and radiation use efficiency of cotton (Gossypium hirsutum) under two sowing methods. *Pak J Agric Sci, 43*, 21-24.

Marengo, J. A., Galdos, M. V., Challinor, A., Cunha, A. P., Marin, F. R., Vianna, M. d. S., . . . Bender, F. (2022). Drought in Northeast Brazil: A review of agricultural and policy adaptation options for food security. *Climate Resilience and Sustainability, 1*(1), e17.

Pereira, P. P. d. S., Da Mata, F. A., Figueiredo, A. C. G., de Andrade, K. R. C., & Pereira, M. G. (2017). Maternal active smoking during pregnancy and low birth weight in the Americas: a systematic review and meta-analysis. *Nicotine & tobacco research, 19*(5), 497-505.

PRAKASH, S. C. DESIGN AND DEVELOPMENT OF PERMANENT RAISED BED SEED-CUM-FERTILIZER PLOT DRILL.

Qureshi, F. Z. (2011). *Activity aware video collection to minimize resource usage in smart camera nodes.* Paper presented at the 2011 8th IEEE International Conference on Advanced Video and Signal Based Surveillance (AVSS).

Rady, M. O., Semida, W. M., Howladar, S. M., & Abd El-Mageed, T. A. (2021). Raised beds modulate physiological responses, yield and water use efficiency of wheat (Triticum aestivum L) under deficit irrigation. *Agricultural water management, 245*, 106629.

Setu, T., Legese, T., Teklie, G., & Gebeyhu, B. (2023). Effect of furrow irrigation systems and irrigation levels on maize agronomy and water use efficiency in Arba Minch, Southern, Ethiopia. *Heliyon, 9*(7).

Shahzad, F., Baig, M. H., Rehman, I. U., Saeed, A., & Asim, G. A. (2022). Does intellectual capital efficiency explain corporate social responsibility engagement-firm performance relationship? Evidence from environmental, social and governance performance of US listed firms. *Borsa Istanbul Review, 22*(2), 295-305.

Singh, R., Kundu, D., & Bandyopadhyay, K. (2010). Enhancing agricultural productivity through enhanced water use efficiency. *Journal of Agricultural Physics, 10*(2), 1-15.

Sokoto, M., Abubakar, I., & Dikko, A. (2012). Correlation analysis of some growth, yield, yield components and grain quality of wheat (Triticum aestivum L.). *Nigerian Journal of Basic and Applied Sciences, 20*(4), 349-356.

Soltani, A., Galeshi, S., Attarbashi, M., & Taheri, A. (2004). Comparison of two methods for estimating parameters of harvest index increase during seed growth. *Field Crops Research, 89*(2-3), 369-378.

Soroush, F., Mostafazadeh-Fard, B., Mousavi, S.-F., & Abbasi, F. (2012). Solute distribution uniformity and fertilizer losses under meandering and standard furrow irrigation methods. *Australian Journal of Crop Science, 6*(5), 884-890.

Tari, A. F. (2016). The effects of different deficit irrigation strategies on yield, quality, and water-use efficiencies of wheat under semi-arid conditions. *Agricultural water management, 167*, 1-10.

Wang, R., Zhang, Q., Ge, J., Ren, W., Zhang, R., Lan, J., . . . Chen, P. (2021). Analysis of SARS-CoV-2 variant mutations reveals neutralization escape mechanisms and the ability to use ACE2 receptors from additional species. *Immunity, 54*(7), 1611-1621. e1615.

Zhang, X., Chen, S., Sun, H., Pei, D., & Wang, Y. (2008). Dry matter, harvest index, grain yield and water use efficiency as affected by water supply in winter wheat. *Irrigation science, 27*, 1-10.

Zhao, W., Liu, L., Shen, Q., Yang, J., Han, X., Tian, F., & Wu, J. (2020). Effects of water stress on photosynthesis, yield, and water use efficiency in winter wheat. *Water, 12*(8), 2127.

Zhou, M., Wang, H., Zhu, J., Chen, W., Wang, L., Liu, S., . . . Yin, P. (2016). Cause-specific mortality for 240 causes in China during 1990–2013: a systematic subnational analysis for the Global Burden of Disease Study 2013. *The Lancet, 387*(10015), 251-272.