Research Article

# Water Productivity from the Main Outfall Drain and Wheat Yield Under Irrigation Scheduling and Leaching Requirements in the Northern Sector, Abu Ghraib Area

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**Abstract** | Effective irrigation techniques are becoming more and more necessary to maintain agricultural output in arid and semi-arid countries due to the increased dependency on saltwater water sources. Using a randomized complete block design (RCBD) with four replicates, a field study was conducted in the northern section of the Main Outfall Drain (MOD), specifically in the Abu Ghraib area, during the fall of 2022–2023. Three irrigation strategies were tested: (I1) irrigation with MOD water following depletion of 50% of the available soil moisture; (I2) the same irrigation approach with an added leaching requirement of 20%; and (I3) using a 40% percent leaching requirement. Water consumption ranged from 405.28 mm in I1 to 480.89 mm in I3. Grain yield followed a similar trend, reaching 4887 kg ha$^{-1}$ in I1, 5653 kg ha$^{-1}$ in I2, and peaking at 5976 kg ha$^{-1}$ in I3. These findings demonstrate that effective irrigation scheduling combined with appropriate leaching practices can substantially enhance water productivity in wheat cultivation, with efficiency values ranging from 2.23 to 2.39 kg m$^{-3}$. These results provide a practical framework for improving saline water management strategies in similar agro-climatic regions facing salinity and water scarcity challenges.

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## Introduction

The Main Outfall Drain (MOD), which connects the Tigris and Euphrates river systems, forms the backbone of Iraq's drainage network, supporting nearly six million dunams of agricultural land in central and southern regions. The drain extends for approximately 565 kilometers, with its surface width ranging from 46 meters at the inlet to approximately 100 meters at the outlet Abdel Sattar and Nouri (2015). Controlling the frequency of irrigation are considered effective strategies in such environments (Al-Obaidi *et al*., 2015; Ati *et al*., 2017; Al-Hasnawi *et al*., 2022). However, challenges such as water scarcity, low-quality irrigation water, and increasing soil salinity have emerged as significant obstacles to crop productivity, necessitating the exploration of alternative irrigation solutions. In response to these limitations, the reuse of marginal-quality water, including saline drainage water, has become increasingly important. Irrigating with saline water is especially vital in regions with limited freshwater availability or shallow groundwater levels, where reducing the groundwater table is also a management goal. The success of using such water sources depends on several interrelated factors, including the salt tolerance of the crop, proper irrigation scheduling, and irrigation system design and management (Hamid *et al*., 2025). Together, these factors influence both water use efficiency and crop yield. Moreover, the strategic use of drainage water for irrigating salt-tolerant crops presents environmental advantages, such as conserving freshwater resources and reducing the volume of saline water requiring treatment or disposal. Accordingly, the present study aims to evaluate the performance of wheat crops irrigated with MOD water of varying salinity levels and leaching requirements, focusing on water demand, growth, yield, and water productivity in the northern sector of the MOD, specifically within the Abu Ghraib region.

Recent studies have increasingly focused on optimizing irrigation under saline conditions to improve crop resilience and water productivity in arid zones. For instance, Ati and Dawod (2024) demonstrated that integrating leaching practices with strategic tillage systems significantly enhances wheat water productivity when using saline water. Similarly, Chawla and Balasaheb (2023) emphasized the importance of irrigation-nitrogen coordination in managing salt stress and maximizing wheat yield. Al-Lami *et al*. (2023) investigated the effects of irrigation intervals and soil amendments on potato and wheat crops under desert conditions, revealing the role of irrigation frequency in mitigating salinity impacts. Moreover, Ayada *et al*. (2024) highlighted the projected influence of future climate change on land and water productivity, underscoring the urgency for adaptable irrigation scheduling methods.

Zidi et al. (2025) provided a comprehensive review of hyperspectral and deep learning methods for monitoring wheat performance under stress, demonstrating the potential of precision tools to assist in real-time salinity management . Also, a recent field trial using biochar and FGD amendments showed that in-season irrigation played a critical role in leaching sodium and chloride from saline-alkali soils, supporting the feasibility of combining amendments with irrigation scheduling . These combined findings reinforce the need to evaluate leaching requirements and water use efficiency under varying saline irrigation regimes as addressed in this study.

The outcomes of this study are expected to guide sustainable irrigation practices in saline-affected regions, contributing to improved food security and water conservation in arid zones.

## Materials and Methods

A field experiment was conducted on the northern part of the Main Outfall Drain (MOD) that extends from the Ishaqi Project outlet located in the north of Baghdad up to the Wasit Governorate, which is approximately 206 kilometers. The trial site was located at Abu Ghraib, specifically at Plot 12 Al-Fakhriyah District. The study was conducted during autumn season 2022-2023. Figure 1 indicates the study area. The land in the study area is characterized by a flat to slightly sloping surface with an average slope of less than 2%. Soil samples were collected from ten randomly selected points, from two depths, 0-0.20 meters, and 0.20-0.40 meters, for the purpose of analyzing the physical and chemical properties of the soil. The samples collected from each depth were mixed properly to give composite samples representing the whole area. They were dried in the lab, then ground before being passed through a 2 mm sieve for analysis. The subsequent analyses to determine major physical and chemical characteristics of the soil before planting were carried out in accordance with procedures described in Adeboye *et al*., 2019. The pipette method was used to analyze particle size distribution and determine soil texture.

### *Experimental treatments and statistical design*

The three irrigation treatments that were used in the experiment on the growth and productivity of wheat were as follows:

1. Irrigation after 50% depletion of available soil moisture, throughout the whole growing season (the control treatment)- I1.
2. Irrigation plus 20% more leaching- I2.
3. Irrigation plus 40% more leaching- I3.

To ensure statistical reliability and account for regional heterogeneity, the field experiment was conducted using a Randomized Complete Block Design (RCBD) with four replications.

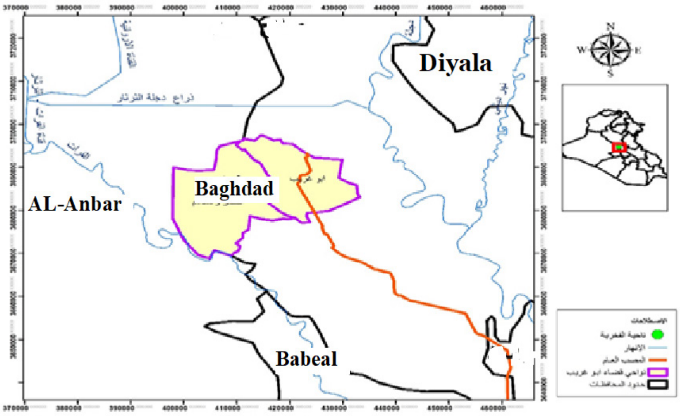


**Figure 1:** *location of study area.*

*The analysis results describe the pre-planting soil condition, both physical and chemical, aas shown in Table 1 (Ati et al., 2023).*

Differences between treatment means were evaluated using the Least Significant Difference (LSD) test at the 0.05 significance level (Zhang *et al.*, 2023).

**Table 1:** *Some characteristics of soil before planting.*

| Property | Units | Soil depth (m) | |
|---|---|---|---|
| | | **0 – 0.20** | **0.20 – 0.40** |
| Sand | g/kg soil | 332 | 244 |
| Silt | | 541 | 520 |
| Clay | | 127 | 236 |
| Soil texture | | Silt loam | Silt loam |
| Bulk soil density | $Mgm^{-3}$ | 1.60 | 1.65 |
| Porosity | | 0.40 | 0.38 |
| Volumetric moisture content at 33 kPa | $cm^3cm^{-3}$ | 0.33 | 0.31 |
| Volumetric moisture content at 1500 kPa | | 0.15 | 0.13 |
| Electrical conductivity EC 1 | $dS\ m^{-1}$ | 4.30 | 3.60 |
| pH | | 7.10 | 7.13 |
| Available nitrogen | $mgkg^{-1}$ soil | 23.11 | 25.03 |
| Available potassium | | 166 | 185 |
| Available phosphorus | | 11.22 | 13.24 |
| Organic matter | $gkg^{-1}$ soil | 7.2 | 4.71 |
| Carbonate minerals | | 220 | 225 |

*Agricultural operations*

The field experiment was carried out in an area of 2,500 $m^2$ with dimensions of 65.7 × 38 meters. A land leveler was used to level the land to attain a uniform and leveled seedbed suitable for planting. The experiment was laid out in three main blocks corresponding to the irrigation treatments. Each block was divided into four replicates, making 12 experimental plots in all. Dimensions of each plot were 45 $m^2$ (15 m × 3 m). To minimize treatment interference, buffer zones were introduced with a spacing of 3 meters between blocks and 2 meters between plots. The wheat cultivar Babylon 113 was sown on November 20, 2022, with a seeding rate of 160 kg $ha^{-1}$. Harvesting was done on May 1, 2023. Before planting, triple superphosphate was applied at the rate of 200 kg $ha^{-1}$. Urea and potassium sulfate were applied first at 200 kg $ha^{-1}$ during the vegetative growth stage and second at flowering at 240 kg $ha^{-1}$. The foliar micronutrients were applied at both stages with a concentration of 60 ppm for Zn, Fe, and Mg, and 20 ppm for Cu. The irrigation water came directly from the Main Outfall Drain (MOD) delivered by a diesel-powered pump connected to a spiral rubber hose (0.07 meters in diameter) which delivered the water through a 100-meter-long linen hose of the same diameter. Soil moisture was monitored on a daily basis throughout the growing season. Irrigation would start when 50% of the water available had been used. The amount of water given was calculated from the soil moisture retention curve until it reached field capacity (FC). This was applied uniformly across all treatments, using the water depth calculated by the equation provided in Al-Kawaz and Gupta (1977).

$$d = (\theta_{fc} - \theta_w) \times D \quad ...(1)$$

$$LR = \frac{EC_{iw}}{(5(EC_e) - EC_{iw})} \quad ...(2)$$

Where; LR= minimum leaching requirement, expressed as a decimal (dimensionless), ECiw= electrical conductivity of the irrigation water (dS $m^{-1}$), ECe= average electrical conductivity of the soil saturation extract in the root zone (dS $m^{-1}$).

*Water-balance equation and calculation of actual water consumptive use ETa*

The actual consumption of wheat was estimated using the water balance equation (Al-Kawaz and Gupta, 1977).

$$(I + P + C) - (ET_a + D + R) = \Delta S \quad ... (3)$$

Where; I= depth of applied irrigation water (mm), P= depth of precipitation (rainfall) during the season (mm), C= capillary rise or upward movement of groundwater (mm), ETa= actual crop evapotranspiration during the growing season (mm), D = depth of drainage or percolated water beyond the root zone (mm), R= surface runoff losses (mm), ΔS = change in soil moisture storage from the beginning to the end of the season (mm).

*Irrigation water productivity*

Water productivity was calculated according to the equation mentioned in [11].

$$Water\ Productivity = \frac{Yield\ (kg\ h^{-1})}{Total\ water\ applied\ (mm)} \quad \ldots (4)$$

Where; Water productivity = water productivity (kg $ha^{-1}$ mm), Yield = total yield (kg $ha^{-1}$), water applied = Depth of irrigation water added (mm).

*Measurement of growth characteristics and yield components*

Plant height (cm $plant^{-1}$): The height of the plant was measured from the soil surface to the base of the spike on the main stem. Measurements were recorded from 25 randomly selected plants within each experimental unit, using the wooden square sampling method.

- Leaf area: The leaf area was measured after flowering by estimating the surface area of the flag leaf, which is considered a key indicator of the plant's photosynthetic capacity.
- Number of tillers: The number of tillers was measured at the full flowering stage. All plants within a 0.3 m × 0.4 m area of each experimental unit were harvested, and the total count was converted to a per-square-meter basis.
- Biological yield and grain yield (kg $ha^{-1}$): Both total above-ground biomass (biological yield) and grain yield were recorded and expressed in kilograms per hectare.

Figure 2 displays selected photographs demonstrating the irrigation practices employed using MOD water in the northern section of the experimental site.

## Results and Discussion

Table 2 presents the components of the water balance equation (Equation 3) for wheat under three irrigation treatments: continuous irrigation (I1), irrigation with plus 20% leaching requirement (I2), and irrigation with MOD water an additional 40% leaching requirement (I3). The results show that the highest seasonal water consumption occurred under the I3 treatment, reaching 480.89 mm across seven irrigation events. In contrast, the lowest water consumption was observed in the I1 treatment, amounting to 405.28 mm, also with seven irrigations. The observed differences in water use among treatments are clearly attributed to the varying depths of irrigation water applied, which were influenced by the different leaching fractions used. These findings are consistent with the expected increase in water application as the leaching requirement increases to manage salt accumulation in the root zone. When comparing the current water consumption values with those reported in previous wheat cultivation studies in central Iraq (Jabbar *et al.*, 2020; Al-Lami *et al.*, 2023; Abdulrazzaq *et al.*, 2018; Chawla and Balasaheb, 2023; Ayada *et al.*, 2024; Ati and Dawod, 2024; Black, 1965), it is evident that the values in this study are relatively lower. This discrepancy can be explained by differences in the number of irrigations, seasonal climatic variations, and rainfall distribution. Earlier studies conducted in the 1970s and 1980s reported seasonal water consumption values ranging from 550 mm to over 600 mm (Phocaides, 2000, Abd El-Wahed *et al.*, 2016). However, those studies often did not account for the effective root zone depth, focusing solely on the volume of water applied and did not face current climate change challenges, such as elevated temperatures and increased evapotranspiration rates. Furthermore, the results of the present study indicated that the duration of crop growth stages was not reduced across treatments, even with variations in irrigation volume. This is a critical observation, as stress from water, heat, or salinity often manifests

**Figure 2:** *Some applied images of the field experiment irrigated with salt water of (MOD).*

**Table 2:** *Irrigation scheduling and water balance for the Wheat growing season 2022-2023 when irrigated with (MOD) water under the surface irrigation system.*

| Treatment | Growth stages | Growth duration (day) | Number of irrigations | Depth of water added at the stage (mm) | Rainwater depth (mm) | Total rain depth) | Total number of irrigations | Total added water depth (mm) | ΔS (mm) | ET calculated by the water balance equation (mm/season) | Quantity of water used ($m^3.ha^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| I1 | Tillering | 20 | 2 | 51.22 | 7.20 | 254.10 | 7 | 206.18 | -55 | 405.28 | 4053 |
| | Elongation | 32 | -- | 0.00 | 122.10 | | | | | | |
| | Booting | 31 | 2 | 54.73 | 17.70 | | | | | | |
| | 50% flowering | 12 | 1 | 30.23 | 0.00 | | | | | | |
| | 100% flowering | 8 | 1 | 24.66 | 0.00 | | | | | | |
| | Grain growth and filling | 25 | 1 | 45.34 | 48.40 | | | | | | |
| | Physiological maturity | 30 | -- | -- | 58.70 | | | | | | |
| I2 | Tillering | 20 | 2 | 51.22 | 7.20 | 254.10 | 7 | 237.03 | -48 | 443.13 | 4431 |
| | Elongation | 32 | -- | 0.00 | 122.10 | | | | | | |
| | Booting | 31 | 2 | 65.68 | 17.70 | | | | | | |
| | 50% flowering | 12 | 1 | 36.23 | 0.00 | | | | | | |
| | 100% flowering | 8 | 1 | 29.56 | 0.00 | | | | | | |
| | Grain growth and filling | 25 | 1 | 54.34 | 48.40 | | | | | | |
| | Physiological maturity | 30 | -- | -- | 58.70 | | | | | | |
| I3 | Tillering | 20 | 2 | 51.22 | 7.20 | 254.10 | 7 | 267.88 | -41 | 480.98 | 4801 |
| | Elongation | 32 | -- | 0.00 | 122.10 | | | | | | |
| | Booting | 31 | 2 | 76.63 | 17.70 | | | | | | |
| | 50% flowering | 12 | 1 | 42.23 | 0.00 | | | | | | |
| | 100% flowering | 8 | 1 | 34.46 | 0.00 | | | | | | |
| | Grain growth and filling | 25 | 1 | 63.34 | 48.40 | | | | | | |
| | Physiological maturity | 30 | -- | -- | 58.70 | | | | | | |

during sensitive phenological stages such as flowering and grain filling. Under extreme conditions such as high temperatures, low vapor pressure, and increased wind speed plants may undergo premature senescence, reduced photosynthetic activity, and shortened grain filling duration. However, such adverse effects were not observed during the 2022–2023 season. Rainfall during critical stages (averaging 107.1 mm) played a key role in mitigating water and salinity stress (Hundi *et al*., 2025; Salman *et al*., 2024). This rainfall helped sustain normal physiological activity and ensured sufficient translocation of photosynthates and carbon assimilates to the developing grains, contributing to stable crop performance under all irrigation treatments. Rainfall during the latter stages of wheat development played a critical role in reducing variations in soil moisture storage (ΔS) between the beginning and end of the growing season. The use of moderately saline irrigation water, with electrical conductivity ranging between 4.0 and 4.6 $dS \cdot m^{-1}$, induced osmotic stress, which can limit plant water uptake by reducing water availability in the root zone. Nevertheless, the rainfall that occurred during key growth stages helped mitigate these negative effects. Figure 3 illustrates the effect of the irrigation treatments on wheat plant height during the 2022–2023 season. Plant height reached 98.56 cm under the MOD-only treatment, 105.22 cm with MOD plus 20% leaching, and 107.76 cm with MOD plus 40% leaching requirement. Figure 4 shows the impact of the same treatments on average leaf area, which measured 47.66 $cm^2$ per plant in the MOD-only treatment, 54.87 $cm^2$ with 20% leaching, and 58.21 $cm^2$ with 40% leaching. Figure 5 presents the average number of tillers per plant, recorded as 11.43 in the MOD treatment, 15.65 with 20% leaching, and 17.22 with 40% leaching. These findings indicate that under all irrigation regimes, the wheat crop received adequate water to support vital physiological and metabolic functions, enabling proper tissue development and sustained growth. The depth of water applied in each treatment was sufficient to meet the crop's moisture requirements, thus preventing any apparent water or salt stress. Although the MOD-only treatment exhibited slightly lower values for plant height, leaf area, and tiller number, these reductions were not statistically significant. The relatively high seasonal rainfall during 2022–2023, totaling 254.10 mm, likely played a major role in buffering the effects of salinity, promoting favorable conditions for crop development even in the absence of additional leaching. This rainfall served as a natural leaching mechanism, improving soil conditions and allowing the crop to grow nearly normally despite exposure to moderately saline irrigation water.

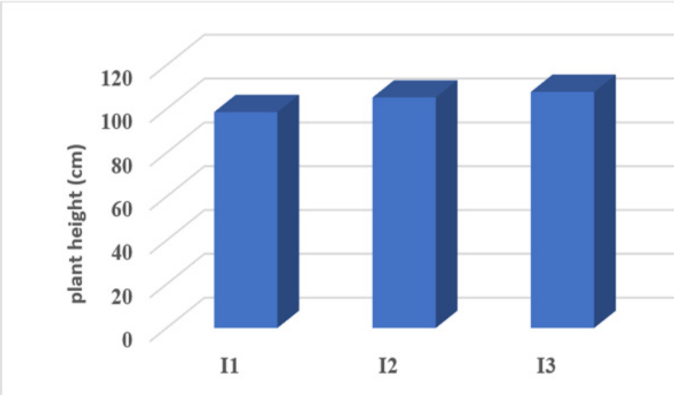


**Figure 3:** *The effect of irrigation treatments with (MOD) water on wheat yield height (cm).*

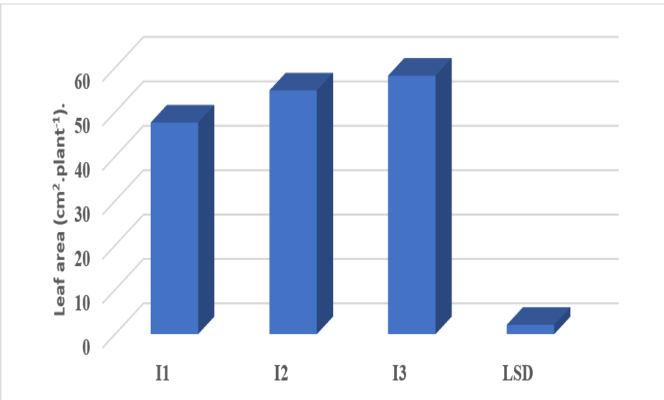


**Figure 4:** *The effect of irrigation treatments with (MOD) water on the leaf area of the wheat crop (cm$^2$ plant$^{-1}$).*

Figure 6 presents the effect of different irrigation treatments on the total grain yield of wheat during the 2022–2023 growing season. Grain yields were recorded as 4,887 kg ha$^{-1}$ for irrigation with MOD water alone, 5,653 kg ha$^{-1}$ with MOD water plus 20% leaching requirement, and 5,976 kg ha$^{-1}$ with MOD water plus 40% leaching requirement. These results were mirrored in Figure 7, which also illustrates the same pattern in grain yield response across treatments.

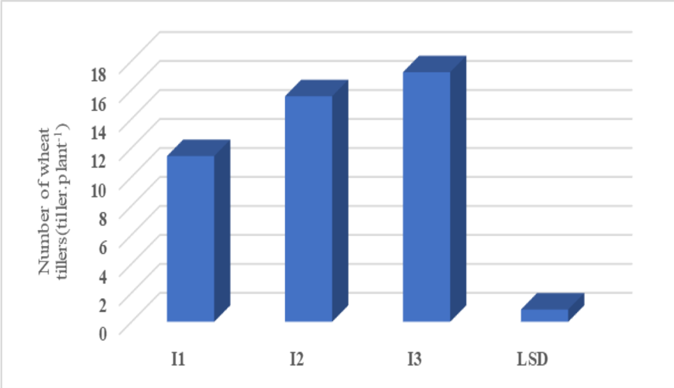


**Figure 5:** *The effect of irrigation treatments with (MOD) water on the number of wheat tillers (tiller plant$^{-1}$).*

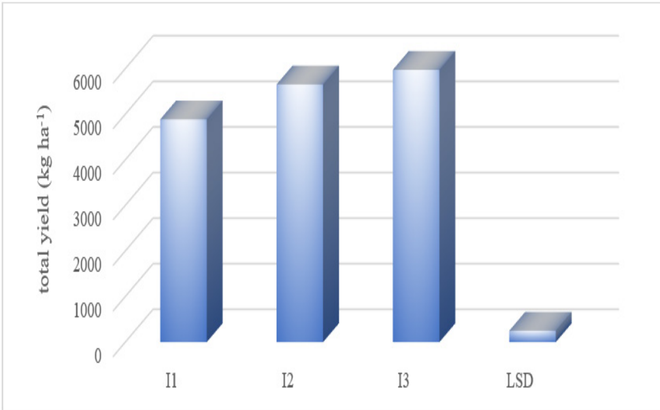


**Figure 6:** *The effect of irrigation treatments with (MOD) water on the total yield of wheat grains (kg ha$^{-1}$).*

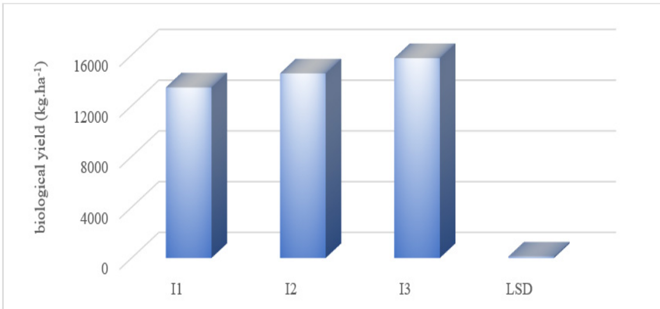


**Figure 7:** *The effect of irrigation treatments with (MOD) water on the biological yield of wheat grains (kg ha$^{-1}$).*

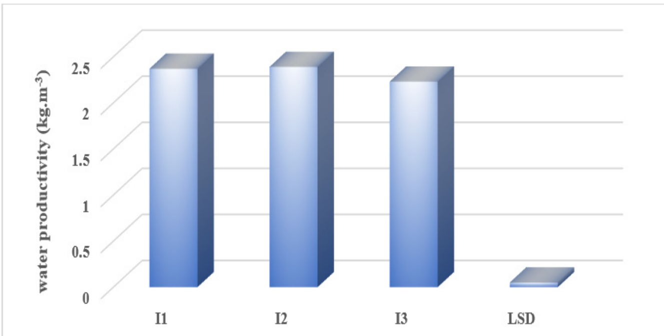


**Figure 8:** *The effect of irrigation treatments with (MOD) water on the total water productivity yield (kg m$^{-3}$).*

The observed yield differences reflect improved root zone conditions that enhanced nutrient uptake by wheat plants. Moreover, seasonal rainfall totaling 254.10 mm played a crucial role in mitigating the adverse effects of saline irrigation water, both on the soil environment and plant physiological performance. The inclusion of leaching requirements also aligns with previous findings, which have shown that increasing the quantity of irrigation water beyond crop evapotranspiration needs helps in reduce salt accumulation in the soil. This is especially critical in saline environments, where high osmotic pressure in the soil solution can inhibit water uptake by plants or result in ion toxicity particularly during early growth stages. Furthermore, salinity can negatively affect the chemical and physical properties of soil, which compromises its function as a productive growing medium. However, the implementation of an effective irrigation management strategy combining irrigation scheduling with appropriate leaching requirements led to marked improvements in water productivity. As shown in Figure 8, water productivity values ranged between 2.23 and 2.39 kg $m^{-3}$. These values are considered excellent, especially when compared to typical wheat water productivity under standard conditions using non-saline river water in non-stressful conditions (Hamid, 2025).

## Conclusions and Recommendations

This study highlights the crucial role of leaching requirements in determining the yield produced per unit of water consumed particularly under favorable rainfall conditions during the 2022–2023 growing season, which received an average of 254.10 mm. This rainfall significantly mitigated the negative effects of saline irrigation water. These strategies may be adapted to dry seasons with low or no rainfall, provided modifications are applied. One proposed approach involves alternating or blending saline and fresh water for irrigation, accompanied by an appropriate leaching fraction and carefully regulated monthly irrigation volumes. This technique aims to maintain the electrical conductivity of the root zone within optimal ranges for crop growth ideally at or below the salinity threshold that would otherwise hinder development. By sustaining a balanced salt concentration in the soil, this method offers a viable solution for managing salinity stress and optimizing crop yield under varying climatic conditions.

## Acknowledgement

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## Novelty Statement

This study is the first field-based evaluation of using moderately saline drainage water from the Main Outfall Drain (EC 4.0–4.6 dS $m^{-1}$) to irrigate wheat under different leaching requirements in the northern sector of the Abu Ghraib area. It quantifies how irrigation scheduling combined with 20–40% leaching fractions can maintain high wheat yields and excellent water productivity (2.23–2.39 kg $m^{-3}$), providing a practical framework for reusing saline drainage water in arid and semi-arid agriculture.

## Author's Contribution

Alaa Salih Ati: Conceptualized the study, designed the experiment, supervised fieldwork, interpreted results, wrote and finalized the manuscript. Alaa Mahdi Akol: Performed data analysis, developed irrigation scheduling and leaching calculations, prepared tables and figures, critically revised the manuscript. Mayada S. Hamed: Conducted sampling and laboratory analyses, organized and validated data, contributed to preparing results and manuscript editing.

*Generative AI and AI-assisted technology statement*

Generative AI and AI-assisted tools were used only for English language editing (grammar and style) after completing the scientific content. All study design, data collection, analysis, and interpretations were performed solely by the authors, who take full responsibility for the accuracy and integrity of the work.

*Conflict of interest*

The authors have declared no conflict of interest.

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