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INTEGRATED EFFECTS OF IRRIGATION SYSTEMS, FERTILIZATION, AND TILLAGE ON YIELD COMPONENTS AND GRAIN QUALITY OF WHEAT (*TRITICUM AESTIVUM* L.) UNDER ARID CONDITION OF IRAQ

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Abstract:
Efficient management of water, nutrients, and soil conditions is essential for improving wheat productivity under irrigated agriculture. This study evaluated the integrated effects of irrigation systems, fertilization, and tillage practices on yield components and qualitative treats of wheat (*Triticum aestivum* L.). The experiment included three irrigation methods (pivot, fixed, and flood irrigation), two fertilization levels (fertilized and unfertilized), and two tillage systems (tillage and no-tillage). Results indicated that irrigation systems significantly influenced yield components and qualitative treats. Pivot The triple interaction among center pivot irrigation, fertilization, and tillage ($I_1T_1F_1$) recorded the highest spike density, reaching 310 spikes/m². For the number of grains per spike, center pivot irrigation achieved superiority with an average of 39 grains/spike. Fertilization and tillage significantly increased this trait, reaching a maximum of 40 grains when the three optimal factors were combined. Concerning 1000-grain weight and test weight, center pivot irrigation recorded the highest averages, reaching 40.13 g and 838.25 g/L, respectively. The results confirmed that fertilization and tillage improved grain filling efficiency and grain density. Vegetative growth results indicated that plant height reached its maximum under center pivot irrigation and fertilization, recording 1.18 m and 1.22 m, respectively.

Keywords: Irrigation Systems, Fertilization, Tillage, Grain Quality, *Triticum aestivum* L.

1. INTRODUCTION

Water is considered the most important source for sustaining life. Due to urban, agricultural, and industrial development, human needs for water have diversified and increased, yet its usage for agricultural purposes remains largely unregulated and inconsistent in many parts of the world (Ingrao *et al.*, 2023). Iraq is one of the countries rich in water resources; however, it has faced waves of drought and is affected by global climate change, leading to a decrease in the water levels of the Tigris and Euphrates rivers.

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Consequently, it has become essential to adopt modern irrigation technologies that reduce the amounts of water used for irrigation (Rizzi and Mollinga, 2024).

The success of any irrigation system is linked to its suitability for the prevailing conditions in the area, focusing on various factors such as climatic conditions, the type of crops grown, water availability, soil quality and texture, and economic considerations. The sprinkler irrigation system offers high flexibility in controlling the amount of water added over time, depending on the infiltration of water into the soil. Sprinkler systems vary widely, including pivot systems and others (Chauhdary *et al.*, 2023).

In all cases of fertilizer use, there was a positive impact on the root and vegetative growth, leading to increased crop yields. However, excessive fertilizer use can lead to several side effects and environmental issues, such as water pollution, gas emissions from fields, and soil degradation (Krasilnikov *et al*., 2022). To ensure higher productivity and improve the efficiency of these lands, it is necessary to add various nutrients, including phosphorus (P), nitrogen (N), and potassium (K), along with other elements in varying ratios depending on soil quality, the type of crop, natural conditions in the area, irrigation methods, and numerous other factors (Pahalvi *et al*., 2021).

Wheat (*Triticum aestivum* L.) is considered one of the most important strategic crops globally due to its vital role in achieving food security and meeting the daily caloric and plant protein needs of populations. Wheat serves as the primary food source for more than one-third of the world's population and is used in producing bread, pastries, pasta, and other essential food products, making it an indispensable element in various dietary systems (FAO, 2024).

The mechanical process applied to the soil is known as tillage, which includes a series of operations performed on the soil to prepare a suitable seedbed and subsequently enhance crop production (Ashraf *et al*., 2022). These practices affect soil moisture content and physical and chemical properties, thereby influencing crop yield at various depths, whether deep, traditional, or no-till (Saleem *et al*., 2020). On the other hand, no-till farming (reduced tillage) is recommended as it preserves soil quality compared to deep or traditional tillage (Basir *et al*., 2017).

The current study aimed to evaluate the performance of the three irrigation systems and two levels for both fertilization and tillage, and determine which is most effective in achieving the highest means for yield components and grain quality of wheat grins.

2. MATERILAS AND METHOD

2.1 Study Area

The experiment was conducted during the 2022–2023 growing season in Asdira Sofla, Al-Shirqat District, south of Nineveh Governorate, Iraq, located about 127 km north of Tikrit along the Tigris River. The experimental field covered approximately 120 dunams within an irrigated agricultural area characterized by widespread use of center-pivot and sprinkler irrigation systems.

2.2 Irrigation Systems

Three irrigation methods were evaluated: center-pivot irrigation (I_1), fixed sprinkler irrigation (I_2), and seepage (surface) irrigation (I_3). These systems represent the most common irrigation technologies used in the study region.

2.3 Crop and Agronomic Practices

Soft wheat (*Triticum aestivum* L.) cv. Cihan was used in the experiment. Seeds were treated against fungal diseases and sown on 15 November 2022 at a rate of 40 kg per dunam using a mechanical planter with 15 cm row spacing. Diammonium phosphate (DAP) fertilizer was applied in fertilized treatments at a rate of 50 kg per dunam at planting. Crop management practices were applied uniformly across treatments throughout the growing season.

2.4 Experimental Design

The experiment was arranged in a randomized complete block design with a split–split plot arrangement and three replications. Irrigation methods were assigned to main plots, fertilization treatments (with (F_1) and without fertilizer (F_2)) to subplots, and tillage treatments (with (T1) and without tillage (T_2)) to sub-subplots.

2.5 Data Collection and Statistical Analysis

Yield components including spikes per square meter, number of grains per spike, thousand-grain weight, and grain bulk density were measured at maturity. Data were analyzed using SAS (version 9.4), and treatment means were compared using Duncan's multiple range test at $P \leq 0.05$.

3. RESULTS AND DISCUSSION

3.1 Plant Height (meter)

The interaction between irrigation methods, fertilization, and tillage had a pronounced effect on plant height (Table 1). The tallest plants were recorded under pivot irrigation combined with tillage and fertilization ($I_1 \times T_1 \times F_1$) (1.26 m), while the shortest plants occurred under flood irrigation without tillage and fertilization ($I_3 \times T_2 \times F_2$) (0.96 m). This trend indicates a strong synergistic effect of adequate water supply, improved soil physical conditions, and nutrient availability on vegetative growth.

The superiority of pivot irrigation can be attributed to its uniform water distribution and reduced moisture stress, which enhance cell elongation and biomass accumulation (Farooq *et al*., 2012). Fertilization significantly amplified plant height across all irrigation and tillage treatments, reflecting the critical role of nutrients—particularly nitrogen—in promoting stem elongation and photosynthetic capacity (Fageria, 2014). Additionally, tillage contributed to increased plant height by improving soil aeration and root penetration, thereby enhancing water and nutrient uptake (Lal, 2004).

The consistently lower plant height observed under flood irrigation, especially when combined with no tillage and no fertilization may result from poor soil structure, uneven moisture distribution, and reduced nutrient availability, which collectively limit vegetative growth (Khan et al., 2017). Overall, these findings align with earlier results in this study (Tables 4.17–4.19) and reinforce the importance of integrated irrigation, fertilization, and tillage management for optimizing plant growth and crop productivity.

3.2 Number of Spikelet per Square Meter (spikelet/m^2)

Table (1) also illustrates the interaction effects of irrigation methods, fertilization, and tillage practices on the number of spikes per square meter. The results demonstrate that the combined influence of these agronomic factors significantly affected spike density, indicating that spike production is highly responsive to management practices.

The highest number of spikes per m^2 (310) was recorded under pivot irrigation (I_1) combined with tillage (T_1) and fertilization (F_1), which was statistically superior to most other treatment combinations. This finding suggests that adequate water distribution under pivot irrigation, when integrated with soil tillage and nutrient application, creates optimal soil physical conditions and nutrient availability, thereby enhancing tiller formation and spike development. Similarly, high values were also observed under the same irrigation and tillage conditions without fertilization (308), indicating that pivot irrigation and tillage play a dominant role in promoting spike density. In contrast, the lowest spike numbers were consistently associated with treatments involving no tillage (T_2) and no fertilization (F_2), particularly under flood irrigation (I_3), which recorded the minimum value (246 spikes/m²). This reduction may be attributed to poor soil structure, limited nutrient availability, and less efficient water use under flood irrigation, especially in the absence of tillage. Flood irrigation can lead to waterlogging and reduced soil aeration, negatively affecting root growth and tiller survival.

Across irrigation methods, fertilized treatments (F_1) generally produced higher spike numbers than unfertilized treatments (F_2), highlighting the importance of nutrient availability in enhancing reproductive growth. Likewise, tilled plots (T_1) consistently outperformed non-tilled plots (T_2), emphasizing the positive role of tillage in improving soil aeration, root penetration, and nutrient uptake.

Overall, the interaction among irrigation method, fertilization, and tillage was significant, with pivot irrigation combined with tillage and fertilization proving to be the most effective management strategy for maximizing spike density. These findings underscore the importance of integrated crop management practices in improving yield components and suggest that optimizing irrigation efficiency alongside proper soil and nutrient management can substantially enhance crop productivity.

Collectively, these results strongly support the concept that maximum spike production is achieved through the integration of efficient irrigation systems, adequate fertilization, and proper soil tillage**.** The superiority of pivot irrigation combined with fertilization and tillage underscores the importance of adopting holistic agronomic practices rather than relying on single management factors. This integrated approach is particularly important in semi-arid and irrigated agricultural systems, where resource use efficiency directly affects productivity and sustainability.

3.3 Grain Number/spike

The interaction between irrigation methods, fertilization, and tillage had a pronounced and statistically significant effect on the number of grains per spike (Table 1), highlighting the importance of integrated crop management practices. The highest grain number per spike (40 grains) was recorded under pivot irrigation (I_1) combined with tillage (T_1) and fertilization (F_1), indicating that optimal water distribution, improved soil physical conditions, and adequate nutrient availability collectively enhance reproductive development. Similar findings have been reported in cereal crops, where efficient irrigation systems such as pivot irrigation improve soil moisture uniformity and reduce water stress during critical growth stages, thereby promoting spike fertility and grain set (Farooq & Azam, 2012; Kang *et al.*, 2017).

Across all irrigation methods, fertilized treatments (F_1) consistently produced higher grain numbers per spike than unfertilized treatments (F_2), regardless of tillage practice. This trend confirms the essential role of mineral nutrition—particularly nitrogen—in enhancing floret survival, pollen viability, and grain filling, which directly contribute to increased grain number per spike (Fageria, 2014). The marked reduction observed in unfertilized plots, especially under flood irrigation (I_3), reflects the combined negative effects of nutrient deficiency and suboptimal water management, which have been shown to impair assimilate supply to developing spikes (Abbas *et al.*, 2019).

Tillage also played a critical role in modifying the effect of irrigation and fertilization. Treatments under conventional tillage (T_1) consistently outperformed those without tillage (T_2), particularly under fixed and flood irrigation systems. Tillage likely improved soil structure, aeration, and root penetration, facilitating better nutrient uptake and water availability, which are essential for spike development and grain formation (Lal, 2004). In contrast, the lowest grain number per spike (26 grains) was recorded under flood irrigation without tillage and fertilization ($I_3 \times T_2 \times F_2$), indicating that poor soil physical conditions combined with inadequate water and nutrient supply severely restrict yield components.

The interaction effects observed in this study support earlier findings that grain number per spike is highly sensitive to environmental and management factors during the pre-anthesis and anthesis stages (Khan *et* al., 2017). Integrated management practices that combine efficient irrigation systems, appropriate soil preparation, and balanced fertilization have been widely recommended as key strategies for improving yield components and overall crop productivity (FAO, 2024; Fageria, 2014). Therefore, the results of this study reinforce the concept that maximizing grain number per spike requires a holistic approach to crop management rather than reliance on a single input.

Table (1): Interaction between Irrigation Methods, Fertilization and Tillage on Number of Spikes/m²

Treatments			Number of Spikes/m²	Grain number/ spike	Plant Height (m)
I_1	T_1	F_1	310^{a}	40^{a}	1.26^{a}
		F_2	308^{a}	39^{ab}	1.25^{ab}
	T_2	F_1	290^{c}	38^{a-d}	1.16^{de}
		F_2	254^{de}	36^{cde}	1.06^{f}
I_2	T_1	F_1	301^{ab}	39^{ab}	1.25^{ab}
		F_2	293^{bc}	39^{abc}	1.21^{bc}
	T_2	F_1	262^{d}	35^{e}	1.14^{e}
		F_2	249^{e}	32^{f}	1.00^{g}
	T_1	F_1	285^{c}	37^{b-e}	1.20^{cd}

I_3		F_2	283^{c}	36^{de}	1.17^{cde}
	T_2	F_1	263^{d}	29^{g}	1.07^{f}
		F_2	246^{f}	26^{h}	0.96^{g}

Means in columns having the same letter(s) are not significantly different at $P \leq 0.05$ according to Duncan Multiple Range test. **I_1** = pivot, **I_2**= fixed, **I_3**= flood. **T_1** = tillage, **T_2** = without tillage. **F_1**= fertilization, **F_2**= without fertilization.

3.4 The 1000-Grain Weight (gram)

The interaction among irrigation method, fertilization, and tillage had a pronounced effect on the 1000-grain weight, indicating the importance of integrated crop management practices (Table 2). The highest 1000-grain weight was recorded under pivot irrigation (I_1) combined with tillage (T_1) and fertilization (F_1) (41.87), while the lowest values were observed under flood irrigation (I_3) without tillage and fertilization (29.33). This pattern reflects the cumulative influence of adequate water supply, improved soil physical conditions, and sufficient nutrient availability on grain filling and assimilate translocation.

These findings are consistent with the main effects shown in Table 9, where pivot irrigation, fertilization, and tillage individually resulted in significantly higher 1000-grain weight compared to flood irrigation, unfertilized plots, and no-tillage systems. Efficient irrigation methods such as pivot irrigation provide more uniform soil moisture and reduce water stress during the grain-filling stage, which is critical for kernel weight development (Farooq & Azam, 2012; Kang *et al.*, 2009). In contrast, flood irrigation may lead to uneven water distribution and temporary anaerobic soil conditions, negatively affecting root activity and grain filling.

Overall, the results demonstrate that maximum 1000-grain weight is achieved when efficient irrigation, adequate fertilization, and proper soil tillage are applied together. These findings agree with previous studies emphasizing that integrated water–nutrient–soil management is essential for optimizing grain yield components and improving cereal productivity under different agro-ecological conditions (Khan *et al.*, 2017; Abbas *et al.*, 2019).

3.4 The specific weight (g/L)

Table (2) also demonstrates a clear and significant interaction among irrigation method, fertilization, and tillage on grain specific weight. The highest specific weight was recorded under pivot irrigation (I_1) combined with tillage (T_1) and fertilization (F_1) (891.00 g/L), whereas the lowest values were observed under flood irrigation (I_3) without tillage and fertilization (741.00 g/L). These results indicate that optimized water delivery, improved soil physical conditions, and adequate nutrient availability act synergistically to enhance grain density and quality.

The superiority of pivot irrigation may be attributed to its uniform water distribution and reduced moisture stress during grain filling, which promotes better assimilate translocation and kernel development (Farooq & Azam, 2012). Similarly, fertilization significantly improved specific weight across all irrigation and tillage combinations, consistent with findings that balanced nutrient supply enhances grain filling and increases test weight (Fageria, 2014). The positive contribution of tillage observed in this study is likely due to improved soil structure, aeration, and root growth, which facilitate nutrient uptake and water use efficiency (Lal, 2004).

Table (2): Interaction between Irrigation methods, Fertilization and Tillage on 1000-Grain Weight (g) and Specific Weight

Treatments			1000-grain weight (g)	Specific Weight (g/L)
I_1	T_1	F_1	41.87^{a}	891^{a}
		F_2	41.43^{ab}	879^{ab}
	T_2	F_1	39.9^{b}	802^{c}
		F_2	37.33^{c}	781^{de}
I_2	T_1	F_1	40.43^{ab}	871^{ab}
		F_2	40.3^{ab}	868^{b}
	T_2	F_1	36.33^{c}	780^{def}
		F_2	32.33^{d}	760^{fg}
I_3	T_1	F_1	36.10^{c}	809^{c}
		F_2	35.97^{c}	796^{cd}
	T_2	F_1	30.33^{e}	762^{ef}
		F_2	29.33^{e}	741^{g}

Means in columns having the same letter(s) are not significantly different at $P \leq 0.05$ according to Duncan Multiple Range test. **I_1** = pivot, **I_2**= fixed, **I_3**= flood. **T_1** = tillage, **T_2** = without tillage. **F_1**= fertilization, **F_2**= without fertilization.

CONCLUSION

With regard to yield components and qualitative treats, the interaction between center pivot sprinkler irrigation, fertilization, and tillage recorded the best values for number of spikes per square meter, number of grains per spike, 1000-grain weight, test weight, plant height.

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