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Response of Wheat to Different Irrigation Levels in Terms of Growth and Grain Yield

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ABSTRACT

Water availability is a major factor influencing wheat growth, yield components, and grain productivity. The present study was conducted to evaluate the response of wheat to different irrigation levels in terms of growth and grain yield. Five irrigation regimes (I1–I5) were evaluated for their effects on plant height, number of tillers, number of spikelets spike⁻¹, 1000-grain weight, grain yield, and harvest index. The results showed that irrigation regimes significantly affected all studied parameters. Plant height increased progressively with increasing irrigation levels, ranging from 69.25 cm under I1 to 88.25 cm under I5. Similarly, the number of tillers increased from 279.12 m⁻² under I1 to 363.10 m⁻² under I5. The number of spikelets spike⁻¹ also increased from 14.72 under I1 to 19.20 under I5, while the 1000-grain weight increased from 34.62 g to 41.95 g under I1 and I5, respectively. Grain yield showed a marked improvement with increasing irrigation levels, increasing from 2540.20 kg ha⁻¹ under I1 to 4480.30, 4990.45, 5425.30, and 5705.40 kg ha⁻¹ under I2, I3, I4, and I5, respectively. The harvest index followed a similar trend, increasing from 27.35% under I1 to 33.02, 33.65, 35.70, and 36.05% under I2, I3, I4, and I5, respectively. The highest values of all measured traits were recorded under I5, whereas the lowest values were observed under I1. The LSD (p=0.05) values were 2.610 cm for plant height, 9.520 m⁻² for tiller number, 1.240 for spikelets spike⁻¹, 2.180 g for 1000-grain weight, 100.25 kg ha⁻¹ for grain yield, and 0.9210% for the harvest index. These findings demonstrate that adequate irrigation substantially improves wheat growth, yield components, and grain productivity. Under the conditions of the present study, the highest irrigation level (I5) resulted in superior crop performance and grain yield, highlighting the importance of appropriate irrigation management for achieving improved wheat productivity.

Introduction

Wheat (*Triticum aestivum* L.) is one of the most important cereal crops worldwide and plays a central role in global food and nutritional security (Ahmed et al., 2023). The availability of water throughout the growing season strongly influences wheat productivity (Kaleri et al., 2024; Igbadun et al., 2007). This factor is particularly important in arid and semi-arid production environments, where rainfall is often insufficient or irregular and irrigation is required to maintain satisfactory crop growth and grain production (Manzoor et al., 2024). (Si et al., 2023) emphasized that irrigation management directly regulates wheat physiological processes, vegetative growth, yield formation, grain quality, and water productivity, making efficient irrigation management increasingly important under conditions of water scarcity and climate change (Mekkei et al., 2014). Water availability affects wheat growth from early vegetative development through reproductive development and grain filling (Kaleri et al., 2026; Kaleri et al., 2024; Baloch et al., 2014). Adequate soil moisture promotes cell division and expansion, leaf area development, photosynthetic activity, nutrient uptake, and tiller formation. Conversely, water deficiency can restrict root development, reduce photosynthesis, accelerate leaf senescence, and ultimately impair biomass accumulation and reproductive development. (Wang et al., 2023) reported that increasing irrigation availability generally improves plant height, leaf area, above-ground biomass, spike number, grains per spike, and 1000-grain weight, although excessive irrigation may reduce water productivity. Irrigation is particularly important during critical growth stages such as tillering, stem elongation, booting, flowering, and grain filling. Water stress during these stages can reduce the formation and survival of productive tillers and negatively affect spikelet development, grain number, and grain weight. Research on wheat has demonstrated that water deficits can substantially reduce spikes per unit area, kernels per spike, and kernel weight, thereby causing considerable reductions in final grain yield. Similarly, recent research has shown that irrigation management can substantially modify wheat yield components and the efficiency with which water is converted into grain yield. (Lu et al., 2021) found that irrigation amount significantly affected spike density, grain number per spike, thousand-kernel weight, and grain yield under different fertigation regimes. However, increasing irrigation does not necessarily result in proportional increases in grain yield or water-use efficiency (Gao et al., 2009). Excessive irrigation can increase water consumption, promote unnecessary vegetative growth, and reduce water productivity (El-Tohory et al., 2016). A four-year study in a semi-arid environment reported that wheat grain yield increased with irrigation up to an optimum level, after which additional irrigation produced little further yield benefit. Likewise, research conducted for arid and semi-arid regions of Pakistan demonstrated that irrigation level substantially affected both wheat grain yield and water-use efficiency, with the optimum irrigation requirement varying according to environmental conditions. The importance of efficient irrigation management is particularly relevant to wheat production in Pakistan, where agricultural water resources are under increasing pressure. Qadir et al. (2007) and Nasr et al. (2016) also highlighted the importance of irrigation and water-management strategies for improving wheat grain yield and water productivity under water-limited conditions in Pakistan. Therefore, determining the crop response to different irrigation levels is essential for identifying irrigation practices that support vigorous crop growth while improving grain productivity. In this context, the present study was conducted to evaluate the response of wheat to different irrigation levels in terms of growth and grain yield, with particular emphasis on plant height, tiller production, spikelet formation, 1000-grain weight, grain yield, and harvest index. The study aimed to determine how variation in irrigation availability influences important growth and yield components and to identify the irrigation level associated with superior wheat performance under the conditions of the experiment.

Materials and Methods

Field Experiment

A field experiment was conducted in 2025 at Rashdi Agriculture Farm, Village Pir Murad Ali Shah Rashdi, Taluka and District Tando Allahyar. The experiment was laid out in a randomized complete block design (RCBD) comprising 12 treatment combinations with three replications, using a plot size of 15 m². Five irrigation regimes were evaluated, ranging from one to five irrigations. The treatments consisted of I₁ = one irrigation at the crown root initiation (CRI) stage, I₂ = two irrigations at CRI and tillering stages, I₃ = three irrigations at CRI, tillering, and jointing/stem elongation stages, I₄ = four irrigations at CRI, tillering, jointing, and booting/heading stages, and I₅ = five irrigations at CRI, tillering, jointing, booting/heading, and milk/grain-filling stages. This arrangement provided a progressive gradient of water availability throughout the wheat growing season.

Statistical Analysis

Data were subjected to analysis of variance (ANOVA) using Statistix 8.1 software. Treatment means were compared using the least significant difference (LSD) test at a significance level of $\alpha = 0.05$ (Steel et al., 1997).

Result

Plant Height (cm)

Table 01 and **Figure 01**, irrigation regimes significantly affected plant height. Plant height increased progressively with increasing irrigation levels, ranging from 69.25 cm under I1 to 88.25 cm under I5. Treatment I5 produced the tallest plants (88.25 cm), followed by I4 (86.35 cm), I3 (76.90 cm), and I2 (74.35 cm), while the shortest plants were recorded under I1 (69.25 cm). The LSD value at the 5% probability level was 2.610 cm, indicating significant differences among irrigation treatments.

Number of Tillers (m^{-2})

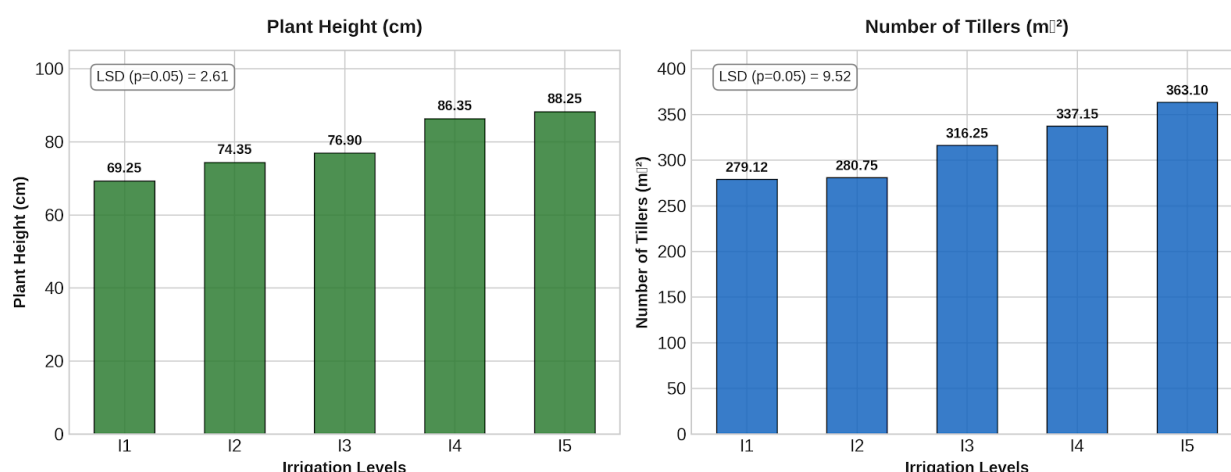
Table 01 and **Figure 01**, the number of tillers m^{-2} was significantly influenced by irrigation treatments. The tiller number increased from 279.12 m^{-2} under I1 to 363.10 m^{-2} under I5. The highest number of tillers was recorded under I5 (363.10 m^{-2}), followed by I4 (337.15 m^{-2}), I3 (316.25 m^{-2}), and I2 (280.75 m^{-2}), whereas I1 produced the lowest tiller number (279.12 m^{-2}). The LSD ($p=0.05$) was 9.520 m^{-2} , confirming significant differences among irrigation regimes.

Table 01 Response of Wheat to Different Irrigation Levels in Terms of Growth and Grain Yield

Irrigation	Plant height (cm)	Number of tiller (m^{-2})
I1	69.25	279.12
I2	74.35	280.75
I3	76.90	316.25
I4	86.35	337.15
I5	88.25	363.10
LSD ($p=0.05$)	2.610	9.520

Figure 01

Response of Wheat to Different Irrigation Levels



Number of Spikelets spike^{-1}

Table 02 and **Figure 02**, irrigation treatments significantly affected the number of spikelets spike^{-1} . The number of spikelets increased progressively from 14.72 spikelets spike^{-1} under I1 to 19.20 spikelets spike^{-1} under I5. The maximum number of spikelets spike^{-1} was observed under I5 (19.20), followed by I4 (18.30), I3 (18.10), and I2 (16.83), while the minimum value was recorded under I1 (14.72). The LSD ($p=0.05$) was 1.240 spikelets spike^{-1} .

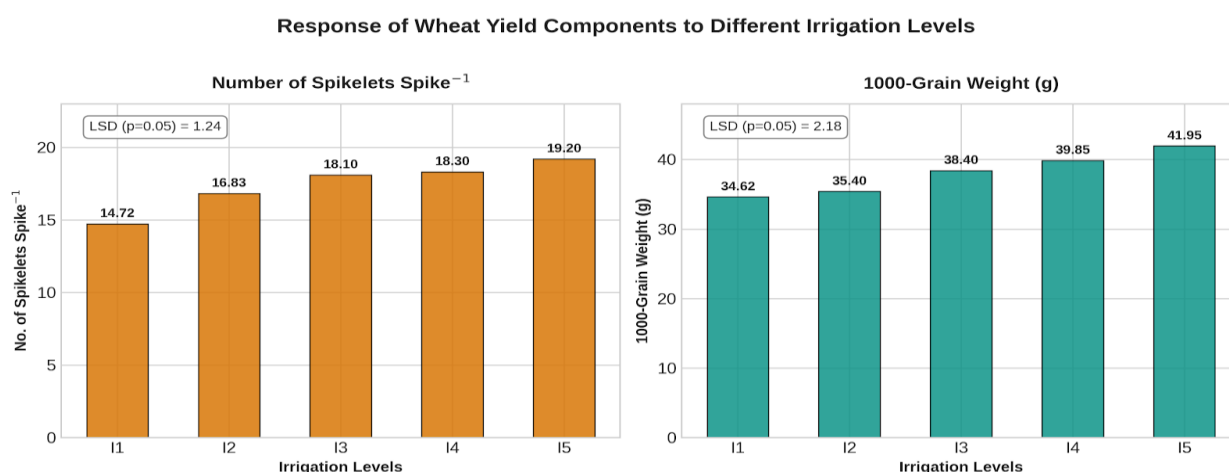
1000-Grain Weight (g)

Table 02 and **Figure 02**, irrigation regimes significantly influenced 1000-grain weight. The grain weight increased with increasing irrigation levels, from 34.62 g under I1 to 41.95 g under I5. The highest 1000-grain weight was recorded under I5 (41.95 g), followed by I4 (39.85 g), I3 (38.40 g), and I2 (35.40 g). The lowest value was observed under I1 (34.62 g). The LSD ($p=0.05$) was 2.180 g, demonstrating significant variation among irrigation treatments.

Table 02 Response of Wheat to Different Irrigation Levels in Terms of Growth and Grain Yield

Irrigation	No. of spikelets spike ⁻¹	1000-grain weight (g)
I1	14.72	34.62
I2	16.83	35.40
I3	18.10	38.40
I4	18.30	39.85
I5	19.20	41.95
LSD ($p=0.05$)	1.240	2.180

Figure 02



Grain Yield (kg ha⁻¹)

Table 03 and **Figure 03**, Irrigation regimes significantly influenced grain yield. Grain yield increased progressively with increasing irrigation levels, ranging from 2540.20 kg ha⁻¹ under I1 to 5705.40 kg ha⁻¹ under I5. The highest grain yield was recorded under I5 (5705.40 kg ha⁻¹), followed by I4 (5425.30 kg ha⁻¹), I3 (4990.45 kg ha⁻¹), and I2 (4480.30 kg ha⁻¹), whereas the lowest grain yield was observed under I1 (2540.20 kg ha⁻¹). The LSD ($p=0.05$) was 100.25 kg ha⁻¹, indicating significant differences among irrigation treatments.

Harvest Index (%)

Table 03 and **Figure 03**, Harvest index was significantly affected by irrigation regimes. The harvest index increased from 27.35% under I1 to 36.05% under I5. The highest harvest index was recorded under I5 (36.05%), followed by I4 (35.70%), I3 (33.65%), and I2 (33.02%), while the lowest value was observed under I1 (27.35%). The LSD ($p=0.05$) was 0.9210%, indicating significant differences among the irrigation treatments.

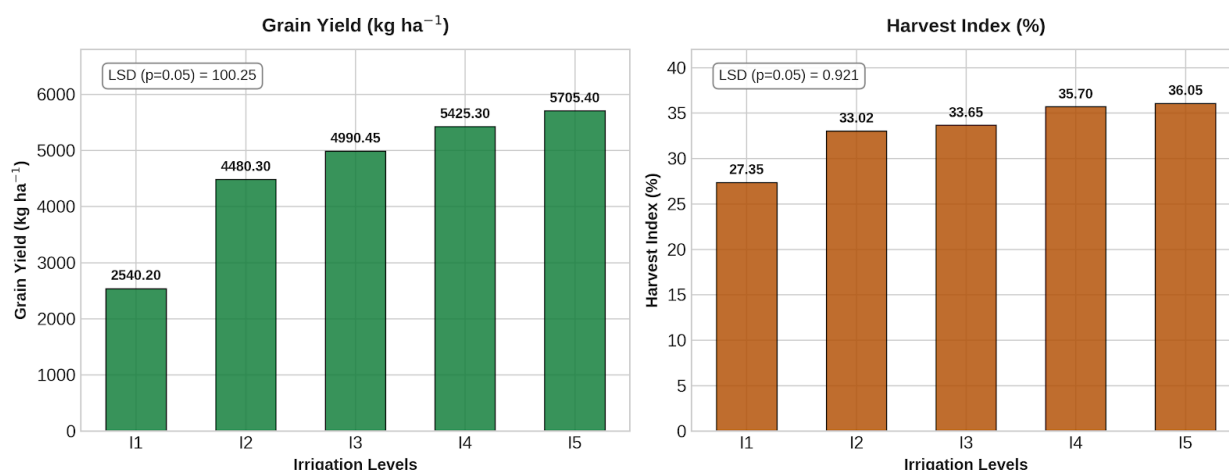
Table 03 Response of Wheat to Different Irrigation Levels in Terms of Growth and Grain Yield

Irrigation	Grain yield (kg ha ⁻¹)	Harvest index (%)
I1	2540.20	27.35
I2	4480.30	33.02

I ₃	4990.45	33.65
I ₄	5425.30	35.70
I ₅	5705.40	36.05
LSD (p=0.05)	100.25	0.9210

Figure 03

Response of Wheat Grain Yield and Harvest Index to Different Irrigation Levels



Discussion

The present study demonstrated that irrigation regime significantly influenced wheat growth and yield attributes. Plant height increased from 69.25 cm under I₁ to 88.25 cm under I₅, indicating that greater water availability promoted vegetative growth. Improved soil moisture enhances cell division, cell expansion, nutrient uptake, and photosynthetic activity, thereby supporting stem elongation. Similar responses were reported by Bhunia et al. (2015), while Damor et al. (2023) observed maximum plant height under irrigation at 100% evapotranspiration. Conversely, water limitation under deficit irrigation can restrict vegetative development, as reported by Swelam et al. (2022) and Alghawry et al. (2021). Tiller production also increased significantly from 279.12 m⁻² under I₁ to 363.10 m⁻² under I₅. Adequate moisture during early growth and tillering promotes leaf development, photosynthesis, and assimilate supply to developing tillers, improving their initiation and survival (Zhang et al., 2022). Sharma and Solanki (2022) similarly reported greater productive tiller numbers under appropriate irrigation, while Alshallash et al. (2022) observed improved spike production with adequate water supply. In semi-arid Sindh, Memon et al. (2021) also reported that water deficiency during tillering substantially reduced wheat growth and yield. The number of spikelets spike⁻¹ increased from 14.72 under I₁ to 19.20 under I₅. Adequate moisture during stem elongation, booting, and reproductive development likely supported spike differentiation and reproductive growth. Fan et al. (2019) reported greater spikelet numbers when irrigation was supplied at critical growth stages, while Cao et al. (2022) found that increasing irrigation frequency improved spikelets spike⁻¹ and other yield components. The lower spikelet number under I₁ may therefore be associated with restricted reproductive development under limited water availability. Similarly, 1000-grain weight increased from 34.62 to 41.95 g with increasing irrigation. Adequate water during grain filling helps maintain photosynthetic activity and assimilate translocation to developing grains, whereas water deficit can accelerate senescence and shorten grain filling. Shirazi et al. (2014) reported greater 1000-grain weight under full irrigation, while Alghawry et al. (2021) and Jha et al. (2019) documented reductions in grain weight under reduced irrigation or irrigation frequency. Grain yield showed the strongest response, increasing from 2540.20 kg ha⁻¹ under I₁ to 5705.40 kg ha⁻¹ under I₅, representing an increase of approximately 124.6%. This improvement was associated with the combined enhancement of plant height, tiller production, spikelet number, and grain weight. Mosaffa et al. (2018) reported maximum wheat yield when irrigation was applied at critical growth stages, while Alshallash et al. (2022) and Alghawry et al. (2021) also observed greater yield under adequate irrigation than under deficit regimes. These findings indicate that insufficient irrigation can constrain both vegetative growth and reproductive development. However, higher irrigation should be considered together with water-use efficiency, particularly in water-limited environments, because maximum grain yield does not necessarily correspond to maximum water productivity. Optimized irrigation can maintain yield while reducing unnecessary water use. The harvest index increased from 27.35% under I₁ to 36.05% under I₅, suggesting

improved partitioning of biomass toward grain production under better water availability. Similar improvements in harvest index under adequate or more frequent irrigation have been reported by Alshallash et al. (2022), Khokhar et al. (2010), and Ngwako and Mashiq (2013). Overall, the consistent improvement in growth, yield components, grain yield, and harvest index under I₅ indicates that adequate moisture throughout critical developmental stages favored wheat productivity under the conditions of the present experiment.

Conclusions

Overall, the results demonstrate a consistent positive response of wheat to increasing irrigation availability. The highest irrigation treatment (I₅) produced the maximum values for plant height, tiller number, spikelets spike⁻¹, 1000-grain weight, grain yield, and harvest index, whereas I₁ consistently recorded the lowest values. The improvement in grain yield appears to have resulted from the combined enhancement of vegetative growth, reproductive development, and grain filling. These findings are broadly consistent with published research showing that adequate irrigation at critical wheat growth stages improves yield components and grain productivity, although the economically and environmentally optimum irrigation level depends on local soil, climate, cultivar, and water availability.

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