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# Effect of Irrigation Scheduling on the Growth and Yield Performance of Wheat (*Triticum aestivum* L.) Varieties

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***Authors' contributions***

*This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.*

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## Abstract

Efficient irrigation scheduling and appropriate varietal selection are essential for sustaining wheat productivity under limited water availability. A field experiment was conducted during the Rabi season of 2018–2019 at the Agronomy Research Farm, Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya, Uttar Pradesh, to evaluate the influence of irrigation scheduling on the growth and yield of wheat varieties. The experiment comprised 12 treatment combinations involving three

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irrigation schedules (0.6, 0.9, and 1.2 IW/CPE ratios) and four wheat varieties (HD-2285, NW-1067, Kundan, and Unnat Halna), arranged in a split-plot design with three replications. An irrigation depth of 60 mm was applied at each irrigation. Growth and yield parameters were recorded and statistically analysed. Irrigation scheduling significantly affected wheat growth, yield attributes, and yield. Irrigation at 1.2 IW/CPE produced the highest plant height, dry-matter accumulation (992.60 g $m^{-2}$), leaf area index, tiller density, spike density, spike length, grains per spike, straw yield, and grain yield (42.87 q $ha^{-1}$). However, its grain yield was statistically comparable with that obtained at 0.9 IW/CPE (41.91 q $ha^{-1}$), while 0.6 IW/CPE produced 34.73 q $ha^{-1}$. Among the varieties, HD-2285 recorded the highest grain yield (43.16 q $ha^{-1}$) and straw yield (58.95 q $ha^{-1}$), whereas Kundan recorded the lowest grain yield (36.92 q $ha^{-1}$). The findings indicate that HD-2285 performed best under the experimental conditions and that 0.9 IW/CPE achieved grain yield comparable with 1.2 IW/CPE.

*Keywords: Wheat; irrigation scheduling; IW/CPE ratio; grain yield; dry-matter accumulation; tiller density; spike characteristics; varietal response; water management.*

## 1. Introduction

Wheat is one of the most important cereal crops in India and many other parts of the world. It contributes substantially to the country's food security. Wheat is highly adaptable and is grown under a wide range of soil and climatic conditions. In India, it is grown mainly in the plains and mountainous regions of northern and southern India. India is the second-largest producer of wheat after China. In India, wheat is cultivated on 31.6 million ha, with a production of 106.88 million tonnes and a productivity of 3.46 tonnes $ha^{-1}$ (Directorate of Economics and Statistics, 2021). Water is one of the most important inputs essential for crop production. Both water shortage and excess directly affect plant growth and development and, consequently, yield and quality. Water is a costly input, and both excess and deficit amounts are harmful to plant growth. Therefore, its judicious use is indispensable. Efficient water use enables better utilisation of other production factors and thus increases yield per unit area and time. Irrigation scheduling is an important crop-management activity that influences the effective and efficient utilisation of water by crops. It determines when the crop should be irrigated and how much water should be applied. Among the recognised criteria for irrigation scheduling, the climatological approach is scientific and has been widely adopted by scientists and researchers worldwide. Evapotranspiration from a full crop cover is closely associated with evaporation from an open pan (Dastane, 1972). Parihar and Tiwari (2003) suggested a relatively practical meteorological approach based on the IW/CPE ratio, defined as the ratio of a fixed amount of irrigation water (IW) to cumulative pan evaporation minus rainfall since the previous irrigation (CPE), as a basis for crop irrigation scheduling. This IW/CPE approach was used to schedule irrigation for wheat in the present study. Selection of a suitable cultivar at an appropriate time is important for obtaining optimum productivity. As wheat is thermosensitive, the choice of a suitable cultivar for different sowing times is particularly important. Concerted and persistent efforts have resulted in the development of several high-yielding wheat strains. Newer high-yielding varieties, although relatively thermosensitive, may perform well under variable climatic conditions. The varieties HD-2285, NW-1067, Kundan, and Unnat Halna have shown promise under irrigated conditions in the eastern Uttar Pradesh region. Recent varietal evaluations further show that wheat genotypes differ in yield-related traits and performance across production environments and water-stress conditions, supporting local assessment of cultivar responses before broader recommendations are made (Alemu et al., 2025; Deepu et al., 2024; Duga et al., 2024; Manjunath et al., 2024; Sewore & Abe, 2024). However, comparative information remains limited on the growth and yield responses of HD-2285, NW-1067, Kundan, and Unnat Halna under IW/CPE-based irrigation schedules in eastern Uttar Pradesh. This context-specific gap restricts evidence-based selection of irrigation schedules and varieties for conditions comparable to the experimental site.

Recent evidence indicates that irrigation scheduling should balance crop water demand with water productivity rather than maximise seasonal water application. Field and synthesis studies show that moderate irrigation targeted at specific growth stages can maintain high wheat yields while limiting deep percolation and inefficient water use, whereas severe deficits and excessive irrigation can reduce yield or water productivity (El-Shafei & Mattar, 2022; Si et al., 2023; You et al., 2022). The response is also cultivar dependent because genotypes differ in root development, tillering, spike formation, and tolerance to soil-water depletion, making evaluation of irrigation × variety combinations agronomically relevant (Pachang et al., 2024; Shang et al., 2020). Therefore, the present experiment was undertaken to quantify the growth and yield responses of four wheat varieties to IW/CPE-based irrigation schedules under the agroecological conditions of eastern Uttar Pradesh.

## 2. Methodology

A field experiment was conducted during the Rabi season of 2018–2019 at the Agronomy Research Farm, Acharya Narendra Deva University of Agriculture and Technology, Kumarganj, Ayodhya, Uttar Pradesh, to study the influence of irrigation schedules on the growth and yield of wheat (*Triticum aestivum* L.) varieties. The farm is located at approximately 26°47′ N latitude and 82°12′ E longitude, at an altitude of 113 m above mean sea level in the Northern Gangetic Alluvial Plain. The study included three irrigation schedules, namely $I_1$ (irrigation at 0.6 IW/CPE ratio), $I_2$ (irrigation at 0.9 IW/CPE ratio), and $I_3$ (irrigation at 1.2 IW/CPE ratio), as the main-plot treatments, and four wheat varieties, namely $V_1$ (HD-2285), $V_2$ (NW-1067), $V_3$ (Kundan), and $V_4$ (Unnat Halna), as the subplot treatments. The experiment was conducted in a split-plot design with three replications. An irrigation-water depth of 60 mm was applied at each irrigation using a Parshall flume. Pan evaporation was recorded using the pan installed at the research-area observatory. Pan evaporation during the interval between successive irrigations was adjusted using a pan coefficient to obtain cumulative pan evaporation (CPE). All other intercultural operations, including weeding, hoeing, and fertiliser application, were kept uniform. At maturity, data were collected for various agronomic traits, namely plant height, tillers $m^{-2}$, grains $spike^{-1}$, 1000-grain weight, grain yield, straw yield, and harvest index.

## 3. Result and Discussion

The results obtained from the present investigation on the yield of wheat varieties, growth components, and yield components are presented in Table 1. The wheat crop responded significantly to the different irrigation schedules in terms of grain yield. The total amounts of irrigation water applied under $I_1$, $I_2$, and $I_3$ were 23, 35, and 41 cm, respectively. Grain yield was highest (42.87 q $ha^{-1}$) under $I_3$ (1.2 IW/CPE ratio), which received six irrigations. This treatment was statistically at par with $I_2$ (0.9 IW/CPE ratio), which received five irrigations, but produced a significantly higher grain yield than $I_1$ (0.6 IW/CPE ratio), which received three irrigations. Grain yield is a manifestation of yield-contributing characters, namely grain weight per ear, ear length, number of grains per ear, effective tillers, and 1000-grain weight. The number of spikes per square metre (Table 1) varied significantly among irrigation schedules. The highest number of spikes per square metre was recorded under $I_3$ (1.2 IW/CPE ratio), followed by $I_2$ (0.9 IW/CPE ratio), whereas the lowest number was recorded under $I_1$ (0.6 IW/CPE ratio). This response may have resulted from the maintenance of adequate moisture in the root zone throughout crop growth, which maintained leaf chlorophyll content and kept the crop green for a longer period. This condition may have increased photosynthetic activity and contributed to higher yield components through greater translocation of photosynthates from source to sink. Similar results were reported by Choplot and Sumeriyan (2013). The lower numbers of effective tillers and spikes per square metre under $I_1$ (0.6 IW/CPE ratio) were possibly due to water stress experienced by the crop during growth.

The higher grain yield under $I_3$ and the statistical similarity between $I_3$ and $I_2$ indicate a diminishing yield response as irrigation supply approaches adequate soil-moisture conditions. Comparable field studies have reported that appropriately timed or moderate irrigation improves spike density, kernels per spike, and grain yield, whereas excessive water application may reduce water productivity without a proportional yield gain (El-Shafei & Mattar, 2022; Jha et al., 2019; You et al., 2022). The present results should therefore be interpreted as evidence of improved yield under the tested moisture regimes rather than as a universal recommendation for maximum irrigation.

Data further indicated that spike length and the number of grains $spike^{-1}$ were significantly influenced by the irrigation schedules (Table 1). $I_3$ (1.2 IW/CPE ratio) produced the maximum spike length and number of grains $spike^{-1}$ and, being statistically at par with $I_2$ (0.9 IW/CPE ratio), was superior to $I_1$ (0.6 IW/CPE ratio). The minimum spike length and number of grains $spike^{-1}$ were observed under $I_1$ (0.6 IW/CPE ratio). As already mentioned, the treatments that received irrigation without stress during the reproductive phase, i.e. $I_3$ and $I_4$, had greater reproductive efficiency, which was primarily responsible for the greater spike length and number of grains $spike^{-1}$. As spike length increased, the number of grains $spike^{-1}$ also increased because the two parameters are closely associated. Similar results were reported by Dhaka et al. (2006) and Nayak et al. (2015).

Maintenance of soil moisture during stem elongation, booting, and reproductive development can protect floret survival and assimilate supply, thereby supporting spike growth and grain set. Supplemental irrigation at critical growth stages has similarly been associated with improved population dynamics and yield components, although the magnitude of the response varies with cultivar architecture and seasonal water availability (Pachang et al., 2024; Shang et al., 2020; Si et al., 2023).

**Table 1. Growth and yield component of wheat varieties as influenced by irrigation scheduling**

| Treatments | Plant Height (cm)at harvest | Dry matter accumulation at harvest ($gm^{-2}$) | Leaf Area Index at 90 days | Number of tillers ($m^{-2}$) at harvest | Number of spike ($m^{-2}$) | Spike Length | Number of grains $spike^{-1}$ | Straw yield ($q\ ha^{-1}$) | Grain yield ($q\ ha^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|
| **A. Irrigation schedules** | | | | | | | | | |
| 0.6 IW/CPE | 75.53 | 872.55 | 4.52 | 367.12 | 256.83 | 7.99 | 40.21 | 48.53 | 34.73 |
| 0.9 IW/CPE | 86.83 | 914.91 | 5.25 | 398.32 | 264.75 | 9.04 | 43.53 | 53.58 | 41.91 |
| 1.2 IW/CPE | 91.10 | 992.60 | 5.44 | 428.32 | 275.40 | 9.55 | 44.14 | 56.39 | 42.87 |
| SEm + | 1.82 | 21.02 | 0.11 | 8.911 | 3.35 | 0.19 | 0.43 | 1.03 | 0.94 |
| CD at 5% | 7.17 | 82.56 | 0.44 | 34.99 | 13.17 | 0.77 | 1.68 | 4.04 | 3.71 |
| **B. Varieties** | | | | | | | | | |
| HD-2285 | 87.03 | 995.89 | 5.36 | 427.52 | 275.93 | 9.50 | 45.03 | 58.95 | 43.16 |
| NW-1067 | 90.83 | 982.96 | 5.50 | 403.20 | 267.83 | 9.07 | 43.03 | 55.95 | 40.64 |
| Kundan | 85.27 | 845.65 | 4.43 | 365.36 | 256.97 | 8.18 | 40.70 | 47.64 | 36.92 |
| U. Halna | 76.37 | 882.25 | 4.99 | 393.60 | 261.90 | 8.68 | 41.73 | 49.60 | 38.62 |
| SEm + | 1.47 | 19.19 | 0.09 | 7.69 | 3.95 | 0.17 | 0.52 | 0.99 | 0.78 |
| CD at 5% | 4.37 | 57.03 | 0.29 | 22.87 | 11.75 | 0.51 | 1.56 | 2.95 | 2.32 |

Grain yield largely depends on dry matter per plant, total dry-matter production, and its distribution to the ear after anthesis. Total dry-matter production differed significantly at harvest. The highest dry-matter accumulation (992.60 g $m^{-2}$) at harvest was recorded under the $I_3$ irrigation schedule. Plant height and leaf area were also highest under $I_3$ compared with the other irrigation treatments. These results agree with those of Chouhan et al. (2017), Jat et al. (2004), Kumar and Pannu (2012), and Zhong et al. (2015). Dry-matter accumulation results from the accumulation of photosynthates in different plant parts and depends on moisture availability. It is associated with increased plant height, tiller production, leaf area, and leaf area index. Leaf area index reflects the efficiency of the photosynthetic process and depends on the extent of the photosynthetic surface. As leaf area increases, light absorption and the rate of dry-matter production also increase until the foliage becomes sufficiently dense to cause mutual shading, resulting in reduced photosynthetic activity in the lower leaves. Increased plant height is a function of cell expansion and depends on cell water potential. In the present study, plant height, number of tillers, and leaf area index were lowest under the $I_1$ irrigation schedule, which was reflected in reduced dry-matter accumulation. Cell division and cell expansion are highly sensitive to moisture stress, and water deficits have a marked effect on leaf area (Begg & Turner, 1976).

The greater plant height, leaf area index, and dry-matter accumulation under $I_3$ are physiologically consistent with reduced water limitation on leaf expansion, canopy persistence, and photosynthetic carbon assimilation. Research under contrasting irrigation methods and soil-moisture thresholds has shown that an adequate but non-excessive water supply can sustain canopy development and biomass production, whereas water deficit accelerates senescence and restricts assimilate formation (Jha et al., 2019; Mehmood et al., 2023; Si et al., 2023).

It was observed that yield components, namely the number of tillers, spike length, number of spikes per unit area, and number of grains $spike^{-1}$, were significantly higher in HD-2285 than in the other varieties, followed by NW-1067 (Table 1). Furthermore, HD-2285 produced significantly higher grain, straw, and biological yields than the other varieties (Table 1). This may be attributed to the inherent capacity of HD-2285 for enhanced vegetative growth and its optimum duration under the prevailing climatic conditions, whereas the other cultivars experienced adverse climatic conditions that resulted in poor development of vegetative and reproductive characters. This finding supports the report of Mahajan et al. (2018). HD-2285 recorded the highest straw yield (58.95 q $ha^{-1}$) and grain yield (43.16 q $ha^{-1}$), whereas Kundan recorded the lowest straw yield (47.64 q $ha^{-1}$) and grain yield (36.92 q $ha^{-1}$). This response may be attributed to the higher genetic potential of HD-2285, including more fertile tillers and greater spike length. Marked variation in yield components and yield among cultivars was also reported by Manjunath et al. (2024).

The superiority of HD-2285 in this experiment indicates a genotype-specific capacity to convert available water and growing-season conditions into productive tillers and grain yield. Genotype × irrigation interactions have been documented for spike number, thousand-grain weight, root development, and water-use efficiency; consequently, varietal rankings may change across rainfall patterns, soils, and irrigation intensities (Jha et al., 2019; Pachang et al., 2024; Shang et al., 2020). Multi-season and multi-location testing would be required before extending the present ranking beyond conditions comparable to the experimental site.

## 4. Conclusion

Irrigation scheduling and varietal selection significantly affected wheat growth, yield attributes, and productivity under the experimental conditions. Irrigation at 1.2 IW/CPE produced the highest plant height, dry-matter accumulation, leaf area index, tiller density, spike density, spike length, number of grains per spike, straw yield, and grain yield. Nevertheless, the grain yield obtained at 1.2 IW/CPE was statistically comparable with that obtained at 0.9 IW/CPE, indicating that the additional irrigation applied under the higher schedule provided only a limited yield advantage. Irrigation at 0.6 IW/CPE resulted in the lowest grain yield because the crop experienced greater moisture stress. Among the evaluated varieties, HD-2285 produced the highest grain and straw yields and performed better for most growth and yield attributes, whereas Kundan recorded the lowest grain yield. Therefore, HD-2285 was the best-performing variety within the study environment. Selection between 0.9 and 1.2 IW/CPE should consider water availability, irrigation cost, and the value of the small additional yield response. These findings are applicable primarily to conditions comparable with the experimental site.

## 5. Limitations

This study was conducted at a single location during one Rabi season; therefore, the findings primarily reflect the environmental and management conditions of the experimental site. The evaluation focused on the main effects of irrigation schedules and wheat varieties, while seasonal variability and irrigation × variety interactions were not assessed in detail. Validation across multiple seasons and locations would strengthen the wider applicability of the observed responses.

## Declaration of AI Use

This manuscript was prepared through the combined contributions of all author(s), including contributions to the study design, data, content development, results, interpretation, and related scholarly work. The author(s) acknowledge the use of Grammarly and ChatGPT to assist with grammar checking, language refinement, reference formatting. These AI-assisted tools were not used as authors and did not replace the intellectual contributions or scholarly judgment of the author(s). All AI-assisted outputs, including content, references, and interpretations, were carefully reviewed, revised, verified, and approved by the author(s). The author(s) accept full responsibility for the accuracy, integrity, and final content of the manuscript.

## Competing Interests

Authors have declared that no competing interests exist.

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