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Effects of Different Levels of Irrigations on Yield and Yield Contributing Characters of Wheat at Bangladesh Condition

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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

A field experiment was conducted at the Bangladesh Agricultural University's Department of Soil Science research site to investigate the impact of varying irrigation regimes on the growth, yield, and yield-related attributes of the wheat cultivar BARI Gom 21 (Shatabdi). The study employed a Randomized Complete Block Design (RCBD) with three replications. The experiments consisted of 6 treatments designated as T_0 = control or no irrigation, T_1 = 1/ crown root initiation (CRI), T_2 = 2/CRI+ tillering, T_3 = 3/ CRI+ tillering + booting, T_4 = 4/ CRI+ tillering + booting + earing, T_5 = 5/ CRI+ tillering + booting + earing + milking number of irrigations at different growth stages. All irrigation treatments were shallow, with a depth of 2 cm. We applied irrigation treatments five times during the crown root initiation (CRI), tillering, booting, earing, and milking. We applied all irrigation treatments in chronological order based on the numbers. Treatment T_5 (5 number of irrigations) exhibited superior performance across all measured agronomic traits. It significantly outperformed other treatments in terms of the highest plant height (90.80 cm), effective tillers number hill^{-1} (5.20), spike length (12.40 cm), grains number spike^{-1} (41.03), grain yield (4.067 t ha^{-1}), 1000-grain weight (55.11 g), straw yield (5.067 t ha^{-1}), and yield plot^{-1}(9.133 t ha^{-1}). In all cases, the non-irrigated or control treatment gave the lowest result. Ultimately, the experiment suggests that five times application of irrigation showed superior results compared to other treatments for successful wheat production.

Keywords: Irrigation; schedules; growth; yield; wheat.

1. INTRODUCTION

Wheat (*Triticum aestivum* L.) is one of the first dominant and important cereal crop in the globe, following rice [1]. Wheat serves as a staple food for approximately 40% of the global population [2]. To meet the escalating global demand for food, driven by a growing human population, wheat, the third most cultivated cereal crop worldwide, must be produced in greater quantities (Food and Agricultural Organization, http://faostat.fao.org). A primary dietary source of plant protein for both humans and animals, it plays a pivotal role in global food systems [3]. In Bangladesh, the second most prevalent staple food crop is wheat, following rice [4]. In 2023, Bangladesh produced 1.23 MMT metric tons of wheat, but due to increasing demand and decreasing production area, the country also imported 3.87 MMT [5]. In Bangladesh, wheat production is low compared to other wheat-growing countries around the world.

Bangladesh grows wheat during the *rabi* season, which spans from November to March. The Rabi season in Bangladesh is characterized by coolness and dryness, which limits the effectiveness of fertilizer due to high evapotranspiration. This, in turn, leads to decreased crop growth and development, ultimately affecting grain yield [6]. In the recent years, in Bangladesh the area irrigated by surface water declined from 76% in 1981 Over the past decades, Bangladesh has witnessed a significant shift in irrigation practices, with a dramatic decrease in surface water usage and a corresponding surge in groundwater reliance. Specifically, the proportion of irrigated land dependent on surface water declined from 76% in 1981 to 23% in 2012, while groundwater irrigation increased from 16% to 80% during the same period. Wheat is a strategic crop and is highly responsive to irrigation water during the short winter season [7]. So, for proper wheat growth and development, optimum water availability at the root zone of the plants during their vital growth stages is critical for wheat production [8, 9]. Insufficient soil moisture affects both seed germination and soil nutrient uptake [10]. The frequency of irrigation also has a significant impact on wheat growth and yield. Proper irrigation scheduling is also important to increase the production of wheat [11]. Irrigation before sowing for proper seed germination, at the CRI stage for root development, and at the booting stage to ensure proper initiation and filling of wheat grains [12]. However, the type of soil and local environmental conditions determine the exact number of irrigations required (Food and Agricultural Organization, http://faostat.fao.org). Light-textured soils usually require more frequent irrigations than those of heavy-textured soils [13]. Winter water scarcity necessitates the development of a suitable irrigation scheme for wheat, ensuring optimal soil and irrigation water utilization [14]. Improving irrigation facilities and improving fertilizer practices can accelerate wheat production in

Bangladesh [15]. Wheat is cultivated in Bangladesh in dry and low humid winter season where evapotranspiration prevails high. To meet up the countries ever increasing demand for wheat it is necessary to boost up the production. Irrigation scheduling on the basis of critical physiological stages of wheat is an age-old practice but information on identification of most critical stage of wheat for irrigation as per availability of water is still lacking. Therefore, we undertook the present study to determine the optimal irrigation schedule necessary for achieving the highest economic wheat yield.

2. MATERIALS AND METHODS

2.1 Experimental Location and Topographic Description

The Soil Science research field at Bangladesh Agricultural University, Mymensingh, Bangladesh, was the site of the experiment. The geographical position of the land is located approximately between the latitudes of 24°26' and 24°54' N and between the longitudes of 90°15' and 90°30 E. The BAU experimental farm belongs to the old Brahmaputra Flood Plain, "Agro-Ecological Zone 9." The experimental site's topography was relatively level, with a medium-high elevation. The land was also moderately well-drained soil and belongs to the Sonatola series of the Old Brahmaputra Flood Plain. Soil samples were collected from various locations within the experimental field at a depth of 0-15 cm prior to wheat sowing and fertilizer application. The collected soil was a dark grey, non-calcareous floodplain soil, and its physical and chemical properties were analyzed.

2.2 Experimental Materials and Treatments Details

We used the wheat variety BARI Gom 21 (Shatabdi) as an experimental material. We collected the variety's seeds from Bangladesh Agricultural Development Corporation (BADC), Mymensingh. We laid out the experiment in a randomized complete block design (RCBD) with 6 treatments and 3 replications. The treatments were as follows: T_0 = No irrigation (control), T_1 = Irrigation at crown root initiation stage, T_2 = Irrigation at CRI+ Tillering stage (TS), T_3 = Irrigation at CRI + TS + Booting stage (BS), T_4 = Irrigation at CRI + TS + BS + Earing stage (ES), and T_5 = Irrigation at CRI + TS + BS +ES + Milking stage.

2.3 Production Procedures of Wheat

The power tiller prepared the experimental plot's land by plowing and cross-plowing it six times. The field was meticulously cleared of all vegetation, including weeds and stubble. Experimental plots were then established in accordance with the predetermined experimental design. We applied 101.2 kg N, 31.4 kg P, 55 kg K, and 19.80 kg S per hectare at the final land preparation, following BARC's (2012) recommendation. We applied two-thirds of the urea and all the TSP, MP, and Gypsum during the final land preparation. We applied the remaining urea 25 days after sowing. We sowed seeds into 2-3 cm deep furrows, using hand rakes to maintain a seed rate of 140 kg ha-1 at a distance of 20 cm between adjacent furrows. Gap filling was done when needed to maintain the required plant population. We performed two hand weeding on 22 days and 50 days after sowing, when the plant reached a height of 15-20 cm and 55-65 cm, respectively. The experimental plots were irrigated by water cannel from a nearby deep tube well.

2.4 Treatment Applications

To assess the impact of irrigation frequency on crop development and yield, five irrigation treatments (T_1-T_5) were implemented. Treatments differed in the number of irrigation events applied at critical growth stages: crown root initiation, tillering, booting, earing, and milking. Each irrigation event provided 2 cm of water. T_1 received a single irrigation at crown root initiation (20 days after sowing, DAS), while T_2, T_3, T_4, and T_5 received two, three, four, and five irrigations, respectively, at the aforementioned stages. The crop was harvested plot-wise when all plants reached maturity (109 DAS)

2.5 Data Collection

Plant height (cm): Panicle height was determined by measuring from the base of the plant to the apex of the tallest spikelet, and the average of these measurements was calculated.

Number of effective tillers plant^{-1}: A random sample of 10 plants from each plot was selected. Those plants with at least one leaf were counted, and the average leaf count per plant was determined.

Number of non-effective tillers plant^{-1}: The mean number of non-effective tillers per plant was determined by counting them on 10 randomly selected plants from each experimental plot.

Spike length (cm): The length of the spike was measured from the selected samples, and their average was calculated.

Number of filled grains spike^{-1}: Grain counts were determined by averaging the number of grains per spike across ten randomly selected spikes from ten plants in each plot.

Weight of 1000 grains (g): A thousand dried, unblemished seeds were randomly selected from the sample plants and their combined mass was determined using an electronic balance."

Grain yield (t ha^{-1}): The harvested grains from each unit plot were dried under the sun, weighed precisely, and then combined with the dry weight of selected plants. The total grain yield for each plot was recorded in tha^{-1}.

Straw yield (t ha^{-1}): Straw from each experimental unit, including that of sampled plants, was sun-dried and weighed to determine final straw yield per plot. This yield was subsequently converted to tons per hectare.

Biological yield (t ha^{-1}): Biological yield was determined using the established equations:

Biological yield (t ha^{-1}) = (grain yield + straw yield) t ha^{-1}

2.6 Statistical Analysis

To assess the significance of yield-contributing characteristics and overall yield, an ANOVA analysis was conducted. Duncan's Multiple Range Test (DMR), as outlined by [16], was employed to compare means for traits with significant F-values.

3. RESULTS

Irrigation schedules significantly impacted wheat yield components and overall yield. Treatment T_5, which is the highest irrigation level, exhibited superior plant growth characteristics, including maximum plant height (90.80 cm) and effective tillers plant^{-1} (5.200) (Fig. 1). Conversely, treatment T_0 (no irrigation) recorded the lowest plant height (78.83 cm) and effective tillers hill^{-1} (3.267). Irrigation also markedly influenced spike length. T5 displayed the longest spikes (12.40 cm), while T_0 exhibited the shortest (8.867 cm). Interestingly, T_4's spike length (12.03 cm) was statistically comparable to T_5's. The overall trend for spike length was $T_5 > T_4 > T_3 > T_2 > T_1 > T_0$. Grains spike^{-1} increased with rising irrigation levels. Irrigated plants consistently produced more filled grains than non-irrigated ones. T_5 had the highest grain number (41.03), followed by T_2 (38.77), while T_0 had the lowest (35.07). While irrigation did not significantly affect 1000-grain weight, T_5 still produced the heaviest grains

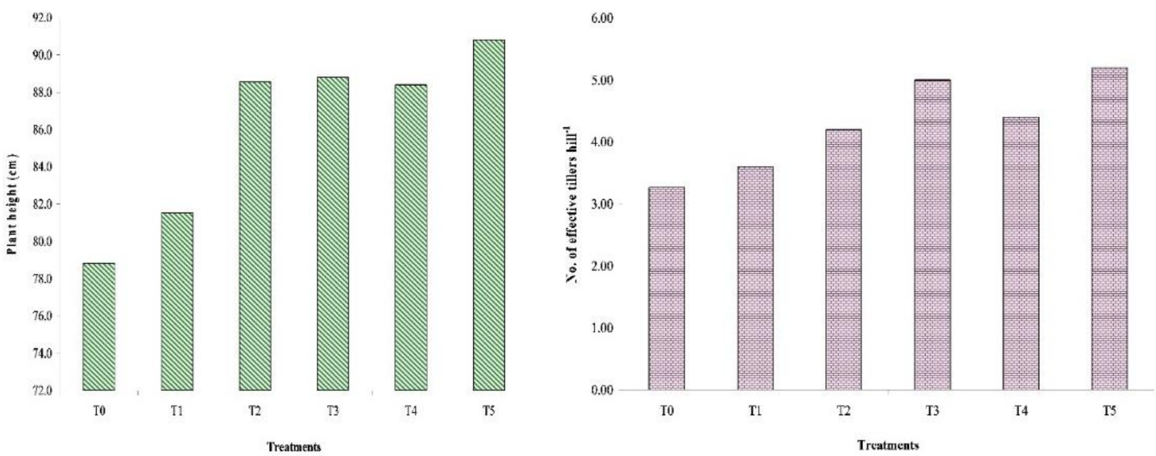

Fig. 1. Effect of different irrigation level on growth characteristics of wheat (plant height, and number of effective tillers plant^{-1})

Table 1. Effects of different levels of irrigation water on the yield and yield components of wheat

Treatments	No of non-Effective tillers hill^{-1}	Spike length (cm)	No. of grain	1000 grain wt. (g)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})	Biological yield (t ha^{-1})
T_0	0.8000 a	8.867c	35.07b	49.55	3.467b	3.633b	7.100b
T_1	0.4000bc	9.567bc	35.20b	50.51	3.500b	3.900b	7.400b
T_2	0.3333cd	10.53abc	38.77a	52.49	3.667b	3.917b	7.583b
T_3	0.4667b	11.13ab	39.20a	54.99	3.533b	3.700b	7.233b
T_4	0.2667d	12.03a	40.63a	53.74	4.017a	4.767a	8.783a
T_5	0.1300e	12.40a	41.03a	55.11	4.067a	5.067a	9.133a
$LSD_{0.05}$	0.081	1.77	2.37	-	0.349	0.419	0.524
Level of significance	**	**	**	NS	**	**	**
SE (±)	0.023	0.561	0.750	1.34	0.111	0.133	0.167
CV (%)	10.08	9.03	3.39	4.41	5.17	5.54	3.67

*Here, figures in a column having common letters do not differ significantly at 5% level of significance. ** = Significant at 1% level of probability * = Significant at 5% level of probability, NS = Not significant, CV% = Coefficient of variation, SE (±) = Standard error of means, T_0 = No irrigation (control), T_1 = Irrigation at crown root initiation stage (CRI), T_2 = Irrigation at crown root initiation stage (CRI) + Tillering stage, T_3 = Irrigation at crown root initiation stage (CRI) + Tillering stage + Booting stage, T_4 = Irrigation at crown root initiation stage (CRI) + Tillering stage + Booting stage + Earing stage, and T_5 = Irrigation at crown root initiation stage (CRI) + Tillering stage + Booting stage + Earing stage + Milking stage*

(55.11 g), and T_0 the lightest (49.55 g). Regarding grain yield, T_5 outperformed all other treatments, yielding 4.067 t ha^{-1}. T_4 closely followed with 4.017 t ha^{-1}, both significantly exceeding the yields of other treatments. Straw yield also varied with irrigation, with T_5 producing the most (5.067 t ha^{-1}) and T_0 the least (3.633 t ha^{-1}). T_5 and T_4 were again statistically superior to the others. The overall ranking for straw yield was $T_5 > T_4 > T_2 > T_1 > T_3 > T_0$. Finally, biological yield, a combination of grain and straw yield, also favoured by T_5 and T_4 treatment. Their yields were statistically similar and significantly higher than the rest of the treatment. The sequence for the remaining treatments was $T_2 > T_1 > T_3 > T_0$ (Table 1).

4. DISCUSSION

The frequency of irrigation significantly influenced the yield components and overall yield of wheat [17]. As the number of irrigations applied at key physiological stages increased, so too did the growth attributes and final yield, with optimal results observed at four irrigations [12]. Adequate soil moisture levels facilitated enhanced plant growth, characterized by increased cell division, expansion, and subsequent stem elongation, resulting in a notable elevation in plant height [12]. The reduced grain yield at T_1 is likely attributable to moisture stress, which hindered root development and nutrient uptake. In line with previous studies [18, 19] demonstrated a positive correlation between nitrogen and irrigation levels and plant height. This growth enhancement is likely due to increased cell division and elongation within the meristematic region. [20] further corroborated these findings, observing the tallest plant development with optimal irrigation at critical growth stages. This, in turn, negatively impacted plant growth and ultimately resulted in lower yields. Conversely, the observed increase in tiller number suggests a beneficial effect of water on vegetative growth. Adequate moisture promotes cell division and elongation, leading to the proliferation of auxiliary buds and increased photosynthesis, which ultimately contributes to a higher number of tillers [21]. The enhanced yield attributes observed in treatments T_4 and T_5 can be attributed to the synergistic effects of ample water availability, a favorable rhizosphere environment for nutrient uptake, and increased photosynthetic efficiency. These factors collectively promote vigorous plant growth, leading to the development of larger and more productive reproductive organs [12]. Consistent with previous findings by [22, 23] our results indicate a positive correlation between irrigation levels and wheat yield components, including tiller and grain production. Supplementary irrigation during the heading-flowering stage likely facilitated the efficient translocation of photosynthates from source organs to developing grains, as suggested by [24]. Increased grain number per spike in the treated plants likely resulted from enhanced floret persistence due to adequate soil moisture, while the reduction in control plots may be attributed to assimilate deficiency and flower abortion under water-stressed conditions during grain filling [25].

The enhanced grain yield of wheat cultivars subjected to four irrigation events at critical stages, namely crown root initiation, tillering, late jointing, and flowering, can be attributed to the synergistic influence of multiple yield-determining factors. These results are in line with [26] and [27]. Our findings suggest that adequate soil moisture, particularly during the early to late flowering stages, is crucial for maximizing wheat yield. While additional irrigation at the milk stage did not significantly impact yield, water stress throughout the growth and reproductive phases negatively influenced photosynthetic activity and resource allocation, ultimately limiting grain development [28] Demonstrated that strategically withholding irrigation at specific growth stages of wheat significantly impacted plant development and grain production.

5. CONCLUSION

The results indicate that irrigation significantly influenced the yield-contributing components and overall yield of wheat. The analysis suggests a strong correlation between irrigation levels and growth characteristics, yield attributes, and final yield. Among all the treatments, applying irrigation five times at the crown root initiation (CRI), tillering, booting, earing, and milking stages (T_5) produced the best results. When irrigation resources are limited in wheat fields, it's recommended to prioritize irrigation at the crown root initiation stage, as this stage is particularly critical for plant development.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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