International Journal of Plant & Soil Science

Volume 38, Issue 4, Page 294-305, 2026; Article no.IJPSS.155921
ISSN: 2320-7035

Effect of Split Application of Nitrogen and Potassium on Growth and Yield of Irrigated Wheat (*Triticum aestivum* L.)

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Authors' contributions

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

Article Information

DOI: https://doi.org/10.9734/ijpss/2026/v38i46048

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://pr.sdiarticle5.com/review-history/155921

Original Research Article

Received: 01/02/2026
Published: 14/04/2026

Abstract

Wheat (*Triticum aestivum* L.) is one of the most important cereal crops globally and serves as a staple food for a substantial proportion of the world's population. The study aims to evaluate the effect of split application of nitrogen and potassium on the growth and yield attributes of irrigated wheat. The experiment was conducted during the rabi season of 2024–25 at SAGE University, Bhopal following a Randomized Block Design with nine treatments and three replications. The treatments consisted of different levels and split applications of nitrogen and potassium, including 100% and 75% recommended dose of fertilizers (RDF: 80:40:40 kg $N:P_2O_5:K_2O$ ha^{-1}), applied at basal, crown root initiation (CRI), and boot leaf stages. The results revealed that split application of nitrogen and potassium significantly enhanced growth parameters

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Cite as: *Hedau, R., Gedam, S., Raygade, S., Pradhan, A. M., Dhakad, A., Pawar, R., … Kher, D. (2026). Effect of Split Application of Nitrogen and Potassium on Growth and Yield of Irrigated Wheat (Triticum aestivum L.). International Journal of Plant & Soil Science, 38(4), 294–305. https://doi.org/10.9734/ijpss/2026/v38i46048*

such as plant height, dry matter production, leaf area index (LAI), and number of tillers per meter row length at different growth stages, except at 30 DAS. Among the treatments, application of 100% RDF with nitrogen and potassium in three equal splits (33:33:33%) at basal, CRI, and boot leaf stages recorded significantly higher plant height (97.6 cm at harvest), dry matter production (96.40 g m^{-1} row length at 90 DAS), LAI (3.36 at 90 DAS), and number of tillers (224.00 m^{-1} row length at 60 DAS), and was found to be at par with other split treatments under 100% RDF. Yield attributes showed variable responses to split nutrient application. Grain weight per spike was significantly increased, with the highest value (1.78 g) recorded under 100% RDF with three equal splits of nitrogen and potassium, which was at par with 25:25:50% split application. However, the number of grains per spike and test weight did not show significant differences, although higher values were observed under the same treatment. The study concludes that split application of nitrogen and potassium, particularly in three equal splits (33:33:33%) at basal, CRI, and boot leaf stages under 100% RDF, is an effective nutrient management practice for enhancing growth and improving yield attributes of irrigated wheat. This approach ensures better nutrient use efficiency and can be recommended for sustainable wheat production under irrigated conditions.

Keywords: Wheat; split application; nitrogen; potassium; growth parameters; yield attributes; nutrient use efficiency; irrigated conditions.

1. Introduction

Wheat (*Triticum aestivum* L.) is one of the most important cereal crops in the world and serves as a staple food for a large proportion of the global population. Belonging to the family Poaceae, it is widely cultivated under diverse agro-climatic conditions and plays a crucial role in ensuring food and nutritional security, particularly in developing countries like India. Wheat is primarily grown during the rabi season under irrigated conditions, especially in the Indo-Gangetic plains, where it contributes significantly to national food grain production. Its grains are rich in carbohydrates, proteins, vitamins, and minerals, making it a vital component of the human diet (Abdin et al., 1996).

The productivity of wheat largely depends on efficient nutrient management, among which nitrogen (N) and potassium (K) are of prime importance. Nitrogen is a key constituent of chlorophyll, amino acids, proteins, and nucleic acids, and it plays a central role in vegetative growth, photosynthesis, and biomass accumulation (Alvi et al., 2015). Adequate nitrogen supply promotes tillering, leaf area development, and ultimately grain yield. However, nitrogen is highly dynamic in the soil and prone to losses through leaching, volatilization, and denitrification, particularly under irrigated conditions. This often leads to low nitrogen use efficiency (NUE) when applied in large single doses (Saha et al., 2010).

In Indian agriculture, particularly in the northern and north-western regions of the country it is typically sown from September to December and harvested between February and May, depending on climatic conditions and sowing time. The crop requires cool temperatures (10–15°C) during sowing and warmer conditions (21–26°C) during grain filling and maturity for optimum growth and yield. Nutritionally, wheat is a rich source of carbohydrates, proteins, vitamins, and minerals, and contributes significantly to human dietary requirements. It contains gluten, a protein complex essential for the baking quality of flour, providing elasticity and structure to baked products. Globally, wheat contributes nearly 28% of the total edible dry matter and up to 60% of daily caloric intake in several developing countries (Sharma et al., 2022).

Potassium, on the other hand, is an essential macronutrient that regulates various physiological and biochemical processes in plants, including enzyme activation, osmotic regulation, photosynthesis, and translocation of assimilates. It enhances plant tolerance to abiotic stresses such as drought and temperature fluctuations, improves water use efficiency, and contributes to better grain filling and quality. Despite its importance, potassium management is often neglected in many wheat-growing regions, leading to suboptimal crop performance and reduced soil fertility over time (Akhter et al., 2017).

Traditional fertilizer application practices, involving basal or limited split doses, do not adequately match the nutrient demand of the crop at different growth stages. This mismatch results in inefficient nutrient uptake and increased losses to the environment. Split application of nitrogen has been widely recognized as an effective strategy to synchronize nutrient supply with crop demand, thereby improving NUE, growth, and yield.

Similarly, split application of potassium can ensure its availability during critical growth stages such as tillering, stem elongation, and grain filling, enhancing nutrient uptake and crop performance (Singh, 2020).

Recent advancements in nutrient management emphasize the importance of balanced and stage-specific application of fertilizers for sustainable crop production. The combined and split application of nitrogen and potassium under irrigated conditions can potentially improve nutrient use efficiency, enhance growth attributes, and increase yield and yield components of wheat. Therefore, optimizing the timing and proportion of nitrogen and potassium application is essential for achieving higher productivity and maintaining soil health (Akhter et al., 2024). In view of the above considerations, the present study was undertaken to evaluate the effect of split application of nitrogen and potassium on the growth and yield of irrigated wheat (*Triticum aestivum* L.).

2. Materials and Methods

2.1 Study Site

A field experiment was conducted during the rabi season of 2024–25 at the Research Farm of SAGE (Sanjeev Agrawal Global Educational) University, Bhopal, Madhya Pradesh, India. The experimental site is situated in the Vindhyan plateau region between 23°05′ to 23°54′ North latitude and 77°10′ to 77°40′ East longitude, at an altitude of about 500 m above mean sea level. The soil of the experimental field was sandy loam in texture with slightly acidic pH (6.26) and low to medium organic matter content. Prior to sowing, soil samples were collected from 0–20 cm depth, air-dried, sieved, and analyzed for physico-chemical properties using standard methods. The climatic condition of the region is semi-arid with hot summers and mild winters. During the crop growth period, the mean maximum and minimum temperatures ranged between 33.1°C and 10.9°C, respectively. The minimum temperature (7.2°C) was recorded in January, while the maximum (33.1°C) was observed in March. Relative humidity varied from 29% to 58% during the cropping season.

2.2 Experimental Design

The experiment was laid out in a Randomized Block Design (RBD) with nine treatments and three replications, comprising a total of 27 plots. The gross plot size was 5 m × 4 m and the net plot size was 4 m × 3.5 m. The spacing between plots and replications was maintained at 0.5 m and 1.0 m, respectively.

2.3 Plant Material

Wheat (*Triticum aestivum* L.) variety ‘Annapurna’ was sown on 23 December 2024 at a seed rate of 100 kg ha^{-1} with a row spacing of 20 cm. The recommended dose of fertilizers (RDF) was 80:40:40 kg N: P_2O_5: K_2O ha^{-1}.

2.4 Treatments Details

The treatments consisted of different levels and split applications of nitrogen and potassium, namely: T_1 (100% RDF with 50% N applied as basal and 50% at 30 DAS), T_2 (100% RDF with 25%, 25%, and 50% N and K applied at basal, CRI, and booting stages, respectively), T_3 (100% RDF with 50%, 25%, and 25% N and K applied at basal, CRI, and booting stages), T_4 (100% RDF with equal splits of 33%, 33%, and 33% N and K at basal, CRI, and booting stages), T_5 (75% RDF with 50% N as basal and 50% at 30 DAS), T_6 (75% RDF with 25%, 25%, and 50% N and K applied at basal, CRI, and booting stages), T_7 (75% RDF with 50%, 25%, and 25% N and K applied at basal, CRI, and booting stages), T_8 (75% RDF with 33%, 33%, and 33% N and K applied at basal, CRI, and booting stages), and T_9 (control with no nitrogen application).

2.5 Trial Management

The land was prepared by ploughing with a mouldboard plough followed by two harrowings to achieve a fine tilth. Bunds were constructed around each plot to facilitate irrigation. Fertilizers were applied as per treatment using urea, single super phosphate (SSP), and muriate of potash (MOP) as sources of nitrogen, phosphorus, and potassium, respectively. Phosphorus was applied as basal, while nitrogen and potassium were applied in split doses according to treatment combinations. Irrigation was applied uniformly before sowing and subsequently at 10-day intervals. A total of ten irrigations were applied, including one flood irrigation and nine sprinkler irrigations. Gap filling was carried out one week after germination to maintain uniform plant population. Observations on growth parameters such as plant height, dry matter accumulation, leaf area, and number of tillers per meter row length were recorded at 30, 60, and 90 days after sowing (DAS) and at harvest. Plant height was measured from the base of the plant to the tip of the longest leaf at early stages and to the base of the spike at later stages. Leaf dry matter production (g m row length^{-1}), Leaf area index, and Number of tillers per meter row length.

$$\text{LAI} = \frac{\text{Leaf area (dm}^2\text{)}}{\text{Land area occupied by plant (dm}^2\text{)}}$$

Yield attributes such as number of grains per spike, grain weight per spike, and test weight (1000-grain weight) were recorded at harvest. The number of grains per spike was determined from ten randomly selected spikes, while grain weight per spike was recorded after threshing. Test weight was measured by weighing 1000 grains from each plot.

2.6 Data Analysis

The experimental data were statistically analyzed using analysis of variance (ANOVA) appropriate for Randomized Block Design, and the significance of differences among treatments was tested at the 5% level of probability.

3. Results and Discussion

3.1 Growth Parameters of Wheat

Significant differences were observed in plant height, number of tillers, dry matter production, leaf area, and leaf area index at different growth stages of wheat as influenced by the split application of nitrogen and potassium.

3.2 Plant Height

The split application of nitrogen and potassium at 100 kg N ha^{-1} and 50 kg K_2O ha^{-1}, respectively, applied at basal, crown root initiation (CRI), and boot leaf stages, significantly influenced plant height at all stages of crop growth, except at 30 DAS (Table 1).

At 60 DAS, the different treatment (T1-T4) has significantly increased the plant height compare to the control (T0). The result revealed that the significantly highest plant height was recorded with the treatment T1, T3 and T4 either respectively 65.1cm, 63.4 cm and 68.8cm (Table 1). All these treatments recorded significantly higher plant height compared to the control plot (54.6 cm), similar as (Mathukia et al., 2014).

At 90 DAS, similar trends were observed. The highest plant height (87.3 cm) was recorded under the treatment with three equal splits of nitrogen and potassium (33:33:33%) applied at basal, CRI, and boot leaf stages. This treatment was statistically at par with 100% RDF applied in the ratio of 25:25:50% (nitrogen and potassium) at basal, CRI, and boot leaf stages, which recorded a plant height of 83.3 cm. Both treatments showed significantly higher plant height compared to the control (68.8 cm), closed as result reported by Sharma et al., (2022).

At harvest, the effect of split application remained significant. The maximum plant height (97.6 cm) was recorded under the treatment receiving three equal splits of nitrogen and potassium (33:33:33%) at basal, CRI, and boot leaf stages. This was found to be at par with the treatment receiving 100% RDF in the ratio of 25:25:50% (nitrogen and potassium), which recorded a plant height of 94.4 cm. Both treatments were significantly superior to the control, which recorded a plant height of 74.4 cm, similar as result reported by (Akhter et al., 2017).

3.3 Dry Matter Production per Meter Row Length

The data on dry matter production recorded at different stages of the crop, viz., 30, 60, and 90 days after sowing (DAS), are presented in Table 2.

Table 1. Effect of split application of nitrogen and potassium on growth traits of irrigated wheat

		Plant height (cm)				Leaf dry matter production (g m row length⁻¹)			Leaf area index			Number of tillers per meter row length		
	Treatment	**30 DAS**	**60DAS**	**90DAS**	**Harvest**	**30DAS**	**60 DAS**	**90 DAS**	**30 DAS**	**60 DAS**	**90 DAS**	**30DAS**	**60 DAS**	**90 DAS**
T1	100% RDF (50: 50% N as basal and 30 DAS)	27.3	65.1	78.9	87.4	25.3	71.51	85.77	1.27	2.95	2.85	112.67	219.33	191.67
T2	100% RDF (25 : 25, 50% N and K as basal, CRI stage and boot leaf stage)	25.1	61.3	83.3	94.4	24.48	65.98	92.87	1.2	2.68	3.12	111.67	202.67	209.33
T3	100% RDF (50 : 25, 25% N and K as basal, CRI stage and boot leaf stage)	27.3	63.4	79.9	88.8	25.59	67.67	87.63	1.31	2.75	2.91	114	204.33	192.33
T4	100% RDF (33 : 33, 33% N and K as basal, CRI stage and boot leaf stage)	26.1	68.8	87.3	97.6	25.07	75.86	96.4	1.23	3.19	3.36	112.33	224	212.33
T5	75% RDF 100% RDF (50: 50% N as basal and 30 DAS)	25.4	58.9	74.3	81.7	24.39	60.79	72.07	1.13	2.53	2.58	110.33	197.33	187.33
T6	75% RDF (25: 25, 50% N and K as basal, CRI stage and boot leaf stage)	23.6	57.4	74.6	85	23.25	54.9	76.97	1.08	2.41	2.62	106.67	190.67	180.67
T7	75% RDF (50: 25, 25% N and K as basal, CRI stage and boot leaf stage)	24.8	58.3	72.1	83.8	24.04	58.21	75.6	1.18	2.45	2.7	110	196	186
T8	75% RDF (33: 33, 33% N and K as basal, CRI stage and boot leaf stage)	23.7	59.7	76.2	85.8	23.75	62.78	81.47	1.1	2.62	2.79	108.33	200.33	190.33
T9	No nitrogen application	22.1	54.6	68.8	74.4	22.11	44.46	68.73	1	2.36	2.52	106.67	187.67	177.67
	S.Em ±.	1.73	4.34	5.71	6.81	0.74	2.47	2.71	0.07	0.12	0.13	6.78	5.82	6.23
	CD at 5%	2.12	5.3	6.99	8.33	2.21	7.42	8.12	NS	0.38	0.39	NS	17.46	18.68

Table 2. Effect of split application of nitrogen and potassium on yield of irrigated wheat

	Treatment	Number of grains per spike	Grain weight per spike (g)	1,000 grain weight (g)
T1	100% RDF (50: 50% N as basal and 30 DAS)	38.4	1.54	39.73
T2	100% RDF (25 : 25, 50% N and K as basal, CRI stage and boot leaf stage)	39.77	1.68	41.3
T3	100% RDF (50 : 25, 25% N and K as basal, CRI stage and boot leaf stage)	38.9	1.6	40.92
T4	100% RDF (33 : 33, 33% N and K as basal, CRI stage and boot leaf stage)	40.83	1.78	41.99
T5	75% RDF 100% RDF (50: 50% N as basal and 30 DAS)	37.13	1.45	39.35
T6	75% RDF (25: 25, 50% N and K as basal, CRI stage and boot leaf stage)	37.67	1.42	40.62
T7	75% RDF (50: 25, 25% N and K as basal, CRI stage and boot leaf stage)	37.9	1.46	39.68
T8	75% RDF (33: 33, 33% N and K as basal, CRI stage and boot leaf stage)	38.17	1.47	38.95
T9	No nitrogen application	36.7	1.14	37.92
	S.Em ±.	0.96	0.053	1.66
	CD at 5%	NS	0.159	NS

At 30 DAS, significant variation in dry matter production was observed among the treatments. The data revealed that the highest dry matter production (25.59 g m^{-1} row length) was recorded with the split application of nitrogen and potassium in the ratio of 50:25:25% applied at basal, CRI, and boot leaf stages. This treatment was found to be at par with other treatments, except the control (no nitrogen application), which recorded the lowest dry matter production (22.11 g m^{-1} row length), same as reported by (Singh, 2020).

At 60 DAS, the effect of treatments was more pronounced. The highest dry matter production (75.86 g m^{-1} row length) was recorded under the treatment receiving three equal splits of nitrogen and potassium (33:33:33%) at basal, CRI, and boot leaf stages. This treatment was statistically at par with 100% RDF applied in two splits (50:50% nitrogen at basal and 30 DAS), which recorded 71.51 g m^{-1} row length. Both treatments produced significantly higher dry matter compared to the control, which recorded 44.46 g m^{-1} row length, (El-Mageed et al., 2023).

At 90 DAS, a similar trend was observed. The maximum dry matter production (96.40 g m^{-1} row length) was recorded with the application of nitrogen and potassium in three equal splits (33:33:33%) at basal, CRI, and boot leaf stages. This treatment was at par with 100% RDF applied in the ratio of 25:25:50% (N and K) at basal, CRI, and boot leaf stages, which recorded 92.87 g m^{-1} row length. Both treatments were significantly superior to the control, which recorded the lowest dry matter production (68.73 g m^{-1} row length), closed as result reported by Belete et al. (2018).

3.4 Leaf Area Index of Wheat

The data on leaf area index (LAI) recorded at different growth stages of the crop, viz., 30, 60, and 90 days after sowing (DAS), are presented in Table 2. The split application of nitrogen (N) and potassium (K) at 100 kg N ha^{-1} and 50 kg K_2O ha^{-1}, respectively, applied at basal, crown root initiation (CRI), and boot leaf stages, significantly influenced the leaf area index of wheat at all stages of crop growth, except at 30 DAS, (Akhter et al., 2024).

At 60 DAS, significant variation in LAI was observed among treatments. The data revealed that the highest LAI (3.19) was recorded with the application of nitrogen and potassium in three equal splits (33:33:33%) at basal, CRI, and boot leaf stages. This treatment was found to be at par with 100% RDF applied in two splits (50:50% nitrogen at basal and 30 DAS), which recorded an LAI of 2.95. Both treatments recorded significantly higher LAI compared to the control (no nitrogen application), which recorded an LAI of 2.36, (Vijayakumar et al., 2019).

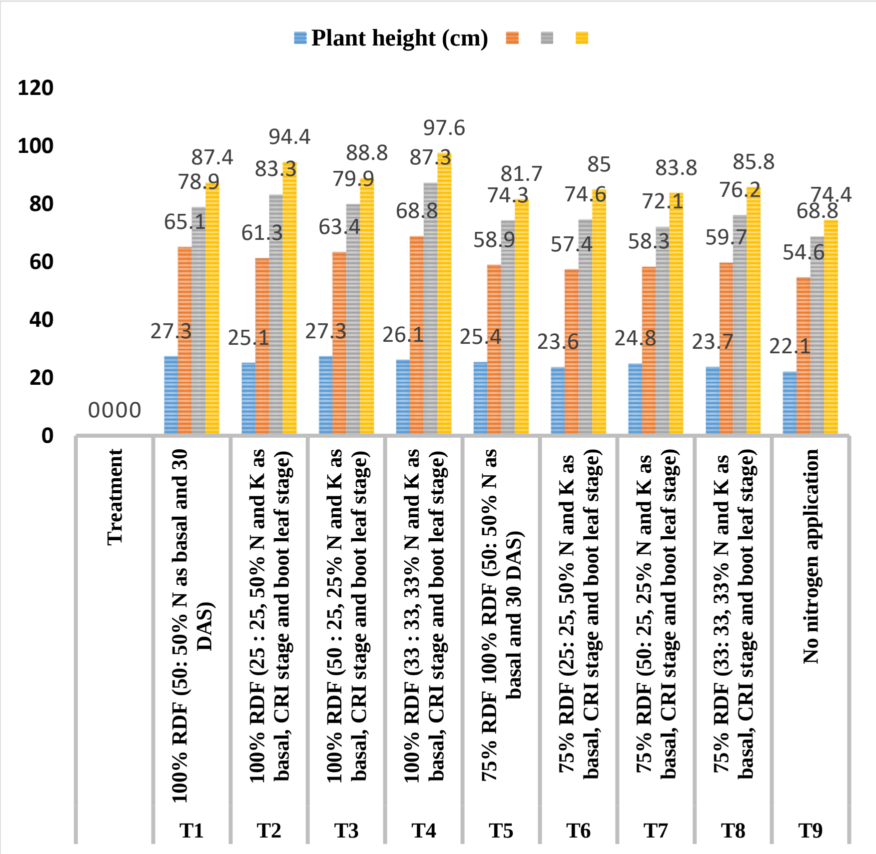

Fig. 1. Plant height (cm) for different treatments

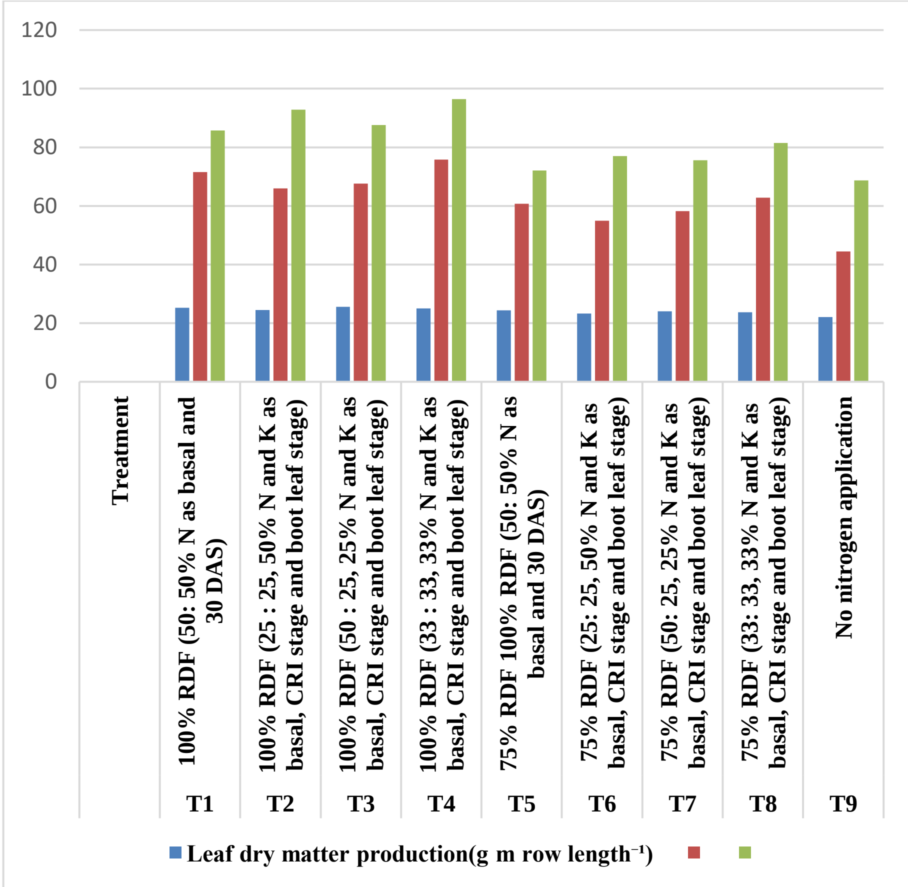

Fig. 2. Leaf dry matter production (g m row length $^{-1}$) for different treatments

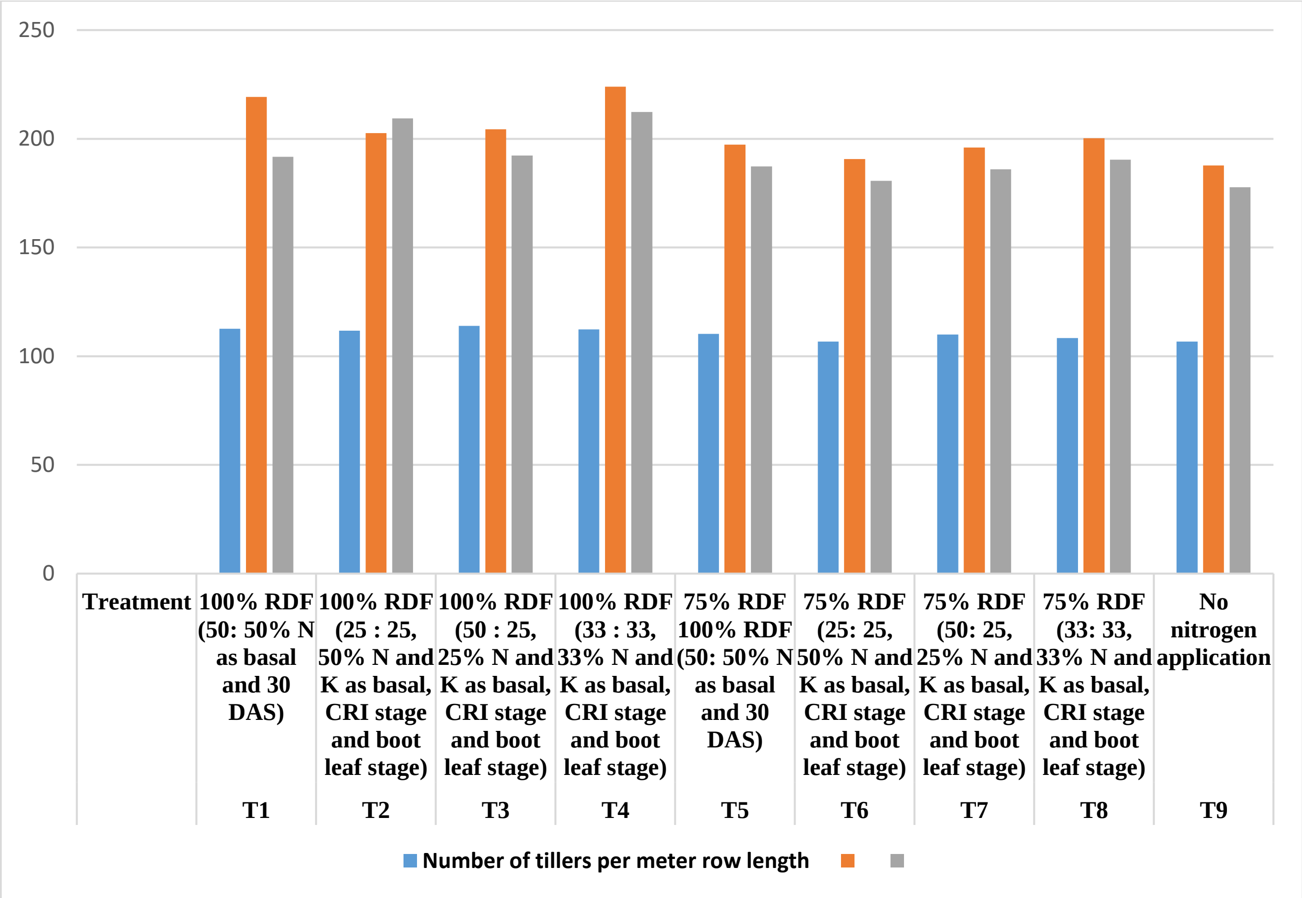

Fig. 3. Number of tillers per meter row length for treatments

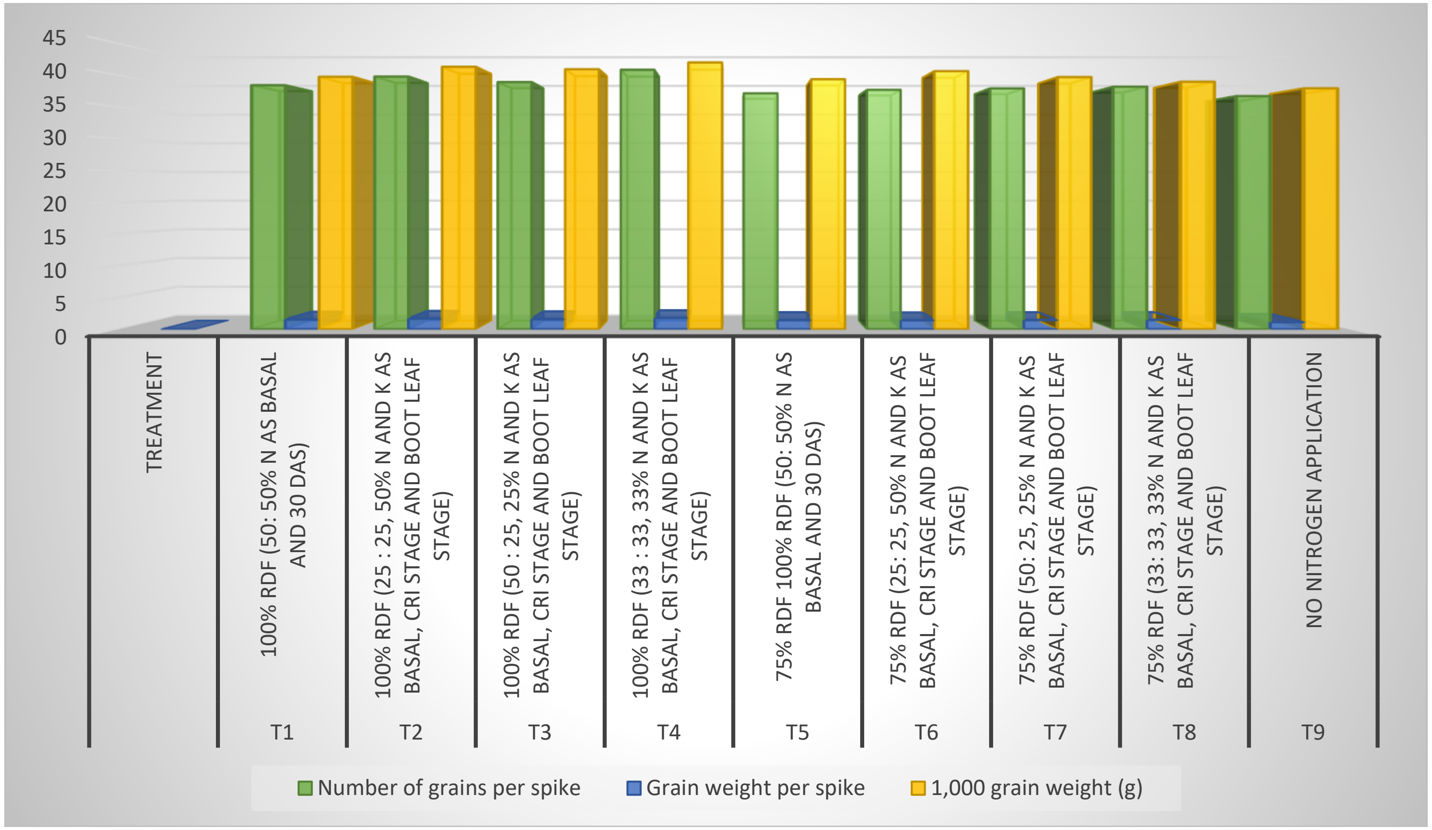

Fig. 4. Number of grains and grain weight per spike for treatments

At 90 DAS, a similar trend was observed. The maximum LAI (3.36) was recorded with three equal split applications of nitrogen and potassium (33:33:33%) at basal, CRI, and boot leaf stages. This treatment was statistically at par with 100% RDF applied in the ratio of 25:25:50% (N and K) at basal, CRI, and boot leaf stages, which recorded an LAI of 3.12. Both treatments were significantly superior to the control, which recorded the lowest LAI (2.52), similar as report reported as Hamani et al. (2023).

3.5 Number of Tillers per Meter Row Length

The data on the number of tillers per meter row length recorded at different growth stages, viz., 30, 60, and 90 DAS, are presented in Table 1. The split application of nitrogen and potassium significantly influenced the number of tillers at all growth stages, except at 30 DAS.

At 60 DAS, significant variation in the number of tillers was observed due to different treatment combinations. The highest number of tillers (224.00 m^{-1} row length) was recorded with three equal split applications of nitrogen and potassium (33:33:33%) at basal, CRI, and boot leaf stages. This treatment was found to be at par with 100% RDF applied in two splits (50:50% nitrogen at basal and 30 DAS), which recorded 219.33 tillers m^{-1} row length. Both treatments recorded significantly higher tiller numbers compared to the control, which recorded the lowest number of tillers (187.67 m^{-1} row length), similar as Sharma et al., 2019).

3.6 Number of Grains per Spike

There was no significant difference observed in the number of grains per spike due to the split application of nitrogen (N) and potassium (K). However, a comparatively higher number of grains per spike (40.83) was recorded under the treatment receiving 100% RDF with three equal split applications (33:33:33% N and K) at basal, crown root initiation (CRI), and boot leaf stages, Singh et al., 2016).

3.7 Grain Weight per Spike

Grain weight per spike was significantly influenced by the split application of nitrogen and potassium. The highest grain weight per spike (1.78 g) was recorded under the treatment receiving 100% RDF applied in three equal splits (33:33:33% N and K) at basal, CRI, and boot leaf stages. This treatment was found to be statistically at par with 100% RDF applied in the ratio of 25:25:50% (N and K) at basal, CRI, and boot leaf stages, which recorded a grain weight of 1.68 g per spike. Both treatments recorded significantly higher grain weight compared to the control (no nitrogen application), which recorded the lowest value (1.14 g per spike), Amani & Behzad, 2020).

3.8 Test Weight (1000-Grain Weight)

No significant difference was observed in the 1000-grain weight due to the split application of nitrogen and potassium. However, the highest test weight (41.99 g) was recorded under the treatment receiving 100% RDF with three equal split applications (33:33:33% N and K) at basal, CRI, and boot leaf stages, Mor et al., 2017).

4. Conclusion

Based on the results of the present investigation, it can be concluded that the split application of nitrogen and potassium had a significant influence on the growth and yield attributes of irrigated wheat (*Triticum aestivum* L.). Among the different treatment combinations, the application of 100% recommended dose of fertilizers (RDF) with nitrogen and potassium applied in three equal splits (33:33:33%) at basal, crown root initiation (CRI), and boot leaf stages consistently produced superior results. This treatment significantly enhanced key growth parameters such as plant height, dry matter production, leaf area index, and number of tillers per meter row length at various growth stages compared to other treatments and the control. The improved growth performance under split nutrient application can be attributed to better synchronization of nutrient availability with crop demand, leading to enhanced nutrient uptake and utilization.

With respect to yield attributes, although the number of grains per spike and test weight did not show significant variation, higher values were recorded under the three equal split application of nitrogen and potassium. Grain weight per spike was significantly improved under this treatment, indicating better translocation of assimilates and grain filling. Overall, the results clearly indicate that the split application of nitrogen and potassium, particularly in three equal splits (33:33:33%) at basal, CRI, and boot leaf stages under 100% RDF, is an effective nutrient management strategy for improving growth performance and yield attributes of irrigated wheat. This approach not only enhances crop productivity but also improves nutrient use efficiency, thereby contributing to sustainable wheat production.

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 the writing or editing of this manuscript.

Competing Interests

Authors have declared that they have no known competing financial interests or non-financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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