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Optimization of sowing date and nitrogen-zinc nutrition for enhancing the growth of wheat (*Triticum aestivum* L.)

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Abstract

A field experiment entitled “Optimization of Sowing Date and Nitrogen-Zinc Nutrition for Enhancing the Growth of Wheat (*Triticum aestivum* L.)” was conducted during the rabi season of 2025 at the Agricultural Research Farm, Rama University, Uttar Pradesh. The study aimed to evaluate the impact of sowing time, nitrogen, and zinc management on growth, zinc enrichment of wheat. The experiment was laid out in a split-plot design with two sowing dates (second fortnight of November and first fortnight of December) and two nitrogen management treatments (N1 and N2) in main plots, and four zinc management treatments in subplots, replicated thrice. Results revealed that sowing in the second fortnight of November (D1) significantly improved growth parameters, yield attributes, and nutrient uptake. Nitrogen applied in four splits (N2) resulted in better growth and yield compared to conventional three-split application. Zinc treatment Z3 (1.5 kg ha⁻¹ basal + foliar spray at Z31 and Z75) significantly enhanced plant growth, grain zinc content, and economic returns. Grain yield, biological yield, and harvest index were significantly influenced by D1, N2, and Z3. Nutrient concentrations in straw and grain varied with treatments, with Z3 and Z4 showing higher zinc enrichment. The highest net returns and benefit:cost ratio were observed with D1, N2, and Z3 combination. Thus, wheat productivity and grain zinc content can be optimized by timely sowing in November, adopting four-split nitrogen application (N2), and integrated zinc management through basal and foliar applications (Z3).

Keywords: Wheat, *Triticum aestivum* L., sowing date, nitrogen management, zinc nutrition, grain zinc enrichment, nutrient uptake, growth and yield, economic returns

Introduction

India currently ranks as the world's second-largest wheat producer. Wheat production during 2023-24 is estimated to reach a record level of about 109.52 million tonnes, compared to 107.86 million tonnes in the previous year (Economics times, 2024). Wheat is one of the most widely traded cereal crops in the world, and the demand for Indian wheat has been increasing globally. During 2023-24, India exported about 20.88 lakh metric tonnes of wheat worth nearly ₹4,037.60 crore, with major export destinations including Nepal, Bangladesh, the United Arab Emirates, Sri Lanka, and Yemen. In India, the major wheat-producing regions are mainly located in the northern states such as Uttar Pradesh, Haryana, and Punjab. (APEDA).

The climate of Uttar Pradesh is mainly humid subtropical with dry winters, while some western parts of the state experience semi-arid conditions. Climate variability is considered one of the major factors affecting crop productivity, even in regions with advanced agricultural practices and high-yield production systems (Bhan and Behera, 2014) [3]. Rising temperatures and moisture stress during the reproductive stage adversely affect winter wheat productivity. Terminal heat stress can reduce plant growth, increase spikelet sterility, and restrict embryo development, ultimately lowering grain number and yield. Higher temperatures during the reproductive phase also increase respiration losses, which further affects crop performance. Therefore, adoption of suitable crop management practices is essential to minimize the negative effects of terminal heat stress on wheat production.

With rising global temperatures, wheat crops are likely to become more fragile in the future. Temperature increases have the potential to drastically lower yields (Aggarwal and Rani, 2009) [1]. Nitrogen has been identified as the most limiting component in plant development and growth, and therefore in crop output, out of all the important nutrients for plants (Ullah *et al.*, 2020) [23]. Nucleic acids, amino acids, Nitrogen is a component of proteins, enzymes, and photosynthetic pigment, which are all essential components of cells (Pandey *et al.*, 2023) [16]. Chlorophyll, the key pigment involved in photosynthesis, contains nitrogen as an essential constituent. A major portion of leaf proteins responsible for photosynthesis also depends on nitrogen, which promotes leaf expansion and overall plant growth. Hence, nitrogen plays a direct role in improving crop development and yield. In wheat, split application of nitrogen not only supplies nutrients during critical growth stages but also enhances grain protein content. Studies have shown that applying nitrogen in two split doses can improve both yield and nitrogen use efficiency (Rahman *et al.*, 2002) [17]. Fertilizer applied to the leaves is more effective than fertilizer applied to the soil because it circumvents many of the possible pathways for nitrogen loss linked to nitrogen delivery to the soil. Rahman *et al.* (2014); Mosali *et al.* (2006) [13, 18]. It is commonly recognized that foliar N treatment and uptake during anthesis is better than soil urea applications because it enables more efficient and quick N transfer to the grain (50 percent absorption in 6 hours) (Wagan *et al.*, 2017) [24].

Human zinc deficiency is now well recognized as a severe nutritional issue. It is more common in areas where grain consumption is high and animal product consumption is low (Roohani *et al.*, 2013) [19]. Zinc has a crucial role in subcellular metabolism. In every enzyme classification, it is a necessary part of the catalytic site or sites of at least one enzyme (Fierke, 2020) [7]. Considering that more than 33 percent of people globally are zinc deficient, and that most of those afflicted live in impoverished nations (Crook, 2011) [4]. According to Singh (2016) [21], zinc deficiency in Indian soils is predicted to increase from 49 to 63 percent by 2025.

Hard wheat is valued for its characteristic golden colour and strong gluten content, making it well suited for bread and pasta production (APEDA). In wheat flour, both the quantity and quality of gluten are key determinants of end-use quality. Gluten, a viscoelastic protein complex in wheat, is responsible for the dough's physical properties, including its elasticity and extensibility, which ultimately influence processing and baking quality (Curic *et al.*, 2001) [5]. Gluten content is assumed to rise with any increase in the flour's total protein concentration. By applying nitrogen at the right time and in the right amount, total protein content may be raised. By increasing the grain's protein content, zinc may be applied both foliarly and basally, increasing gluten and the gluten index (Kinaci and Kinaci, 2019) [9]. By influencing the glutenin interlinking chain, zinc supplementation can change the structural and rheological characteristics of wheat (Liu *et al.*, 2015) [11].

Growth stage scales such as Feekes, Zadoks, and Haun are widely used in agriculture to determine the appropriate timing for input applications in crops. Among these, the Zadoks scale provides a more detailed description of wheat development. It classifies the wheat growth cycle into 10 main stages, which are further divided into finer sub-stages, resulting in a numerical scale from 00 to 99 that covers the entire life cycle of the wheat plant.

Materials and Methods

The field experiment was conducted during the Rabi season of 2025 at Agronomy Research farm of Rama University, Kanpur Uttar Pradesh. The soil of the experimental field was sandy clay loam in texture, neutral in reaction (pH 7.2), which is common in the district's alluvial soils. The soil was low in available nitrogen ($246.60 \text{ kg ha}^{-1}$) as determined by the alkaline permanganate method (Subbiah and Asija, 1956). The available phosphorus content was medium (14.5 kg ha^{-1}), estimated by Olsen's method (Olsen *et al.*, 1954). The soil was found medium to moderately high in available potassium ($294.40 \text{ kg ha}^{-1}$), determined through the flame photometric method (Metson, 1956) at 0-15 cm soil depth prior to the initiation of the experiment. These fertility levels are generally representative of the Indo-Gangetic alluvial soils of the district.

The experiment was laid out in a Split Plot design (SPD) with three replications comprising in main plot Sowing time Second fortnight of November D1, The first fortnight of December D2 and Nitrogen management, namely: 150 kg ha^{-1} Nitrogen [$70 \text{ kg basal} + 40 \text{ kg at Z20 (main shoot only)} + 40 \text{ kg at Z37 (flag leaf visible)}$], 150 kg ha^{-1} Nitrogen [$70 \text{ kg basal} + 35 \text{ kg at Z20 (main shoot only)} + 35 \text{ kg at Z37 (flag leaf visible)} + 10 \text{ kg as } 2\% \text{ urea application at Z60 (beginning of anthesis stage)}$]. Sub plot Zinc management 0 kg ha^{-1} Zinc (No Zinc) Z1, 2.5 kg ha^{-1} Zinc as basal Z2, 1.5 kg ha^{-1} Zinc as basal + $0.50\% \text{ ZnSO}_4$ spray at Z31 (stem elongation) + 0.50% at Z75 (milking) Z3, 1.5 kg ha^{-1} Zinc as basal + $0.50\% \text{ ZnSO}_4$ spray at Z60 (Anthesis) + $0.50\% \text{ ZnSO}_4$ spray at Z85 (Dough stage) Z4. The wheat variety HD-2967.

Result and Discussion

A. Growth Parameter

1. Plant height (cm)

Table No.1 show the data on Plant height increased progressively with crop age, showing rapid growth at early stages and a gradual increase thereafter up to harvest. Sowing time significantly influenced plant height across growth stages, with maximum growth observed during mid-November. Nitrogen effect was non-significant up to 90 DAS but became significant at harvest, where N2 recorded higher plant height than N1. Overall, plant height showed consistent improvement with crop advancement and management practices. Similar result reported by (Asseng *et al.*, 2011), (Kumar 2013) [2, 10].

Different zinc management practices significantly influenced plant height over time. Z2 (2.5 kg ha^{-1} Zn as basal application) resulted in the tallest plants at 30 and 60 DAS, while Z1 (no zinc) recorded the lowest plant height. Treatments Z3 and Z4 were statistically similar, with Z3 showing the maximum plant height at 90 DAS and at harvest. Similar result stated by (Xue *et al.*, 2021), (Nie *et al.*, 2017) [15, 25].

Significant interaction effects were observed among sowing time, nitrogen, and zinc management at different growth stages. At 60 DAS, D1Z2 recorded the tallest plants, while at 90 DAS and harvest, D1Z3 showed the maximum plant height. The interaction effect of nitrogen and zinc was also significant, with N2Z2 performing better at 60 DAS compared to N1Z2 and N1Z3. At harvest stage, the highest plant height was recorded in the combinations D1N2, D1Z3, and N2Z3.

2. No. of tillers per running meter

Table No 2 exhibit data on The number of tillers per running meter increased steadily with crop age, showing rapid growth at early stages and a gradual increase from 90 DAS to harvest.

Sowing time significantly influenced tiller production, with maximum increase observed during the second fortnight of November. Nitrogen effect was non-significant up to 90 DAS but became significant at harvest, where N₂ recorded higher tiller numbers compared to N₁, although both were statistically similar up to 90 DAS. Similar result reported by (Mishra *et al.* 2002), (Kumar 2013) [10, 12].

The data indicate that zinc management significantly affected the total number of tillers at different growth stages. Across both years, Z₂ (2.5 kg ha⁻¹ Zn as basal application) recorded the highest number of tillers at 30 and 60 DAS. However, at 90 DAS and harvest, Z₃ showed the maximum tiller production, while Z₁ (no zinc application) consistently recorded the lowest number of tillers. Similar result reported by (Sehgal *et al.*, 2018), (Farooq *et al.*, 2014) [6, 20].

Significant interaction effects were observed between nitrogen and zinc management as well as between sowing time and zinc management. At 60 DAS, the highest tiller number was recorded in D1Z₂ and N1Z₂, while at 90 DAS and harvest, D1Z₃ and N1Z₃ showed maximum tiller production.

3. Shoot dry matter accumulation (g m⁻¹)

Shoot dry matter accumulation increased progressively from 30 DAS up to harvest under the influence of sowing time, nitrogen, and zinc management. Sowing during the second fortnight of November resulted in higher dry matter accumulation. Although N₁ showed comparatively higher values at 30, 60, and 90 DAS, the effect of nitrogen management remained non-significant up to

90 DAS but became significant at harvest. Similar result reported by (Gholami *et al.*, 2011), (Statkevičiūtė *et al.*, 2022) [8, 22]. Significant differences in shoot dry matter accumulation were observed across all growth stages due to zinc management. Z₂ (2.5 kg ha⁻¹ Zn as basal application) recorded the highest values at 30 and 60 DAS, while Z₃ showed the maximum shoot dry matter accumulation at 90 DAS and at harvest. Similar result reported by (Neenu and Ramesh, 2020), (Farooq *et al.*, 2014) [6, 14].

4. Leaf area index

Leaf area index increased from 30 to 60 DAS and then showed a slower rate of increase from 60 to 90 DAS. Sowing during the second fortnight of November resulted in notable variation in LAI. Although N₁ showed comparatively higher values at 30, 60, and 90 DAS, the effect of nitrogen management on leaf area index was non-significant when treatments were compared. Similar result reported by (Neenu and Ramesh, 2020), (Farooq *et al.*, 2014) [6, 14].

Significant variation in leaf area index was observed across all growth stages due to zinc management. Z₂ (2.5 kg ha⁻¹ Zn as basal application) recorded the highest values at 30 and 60 DAS, while Z₃ showed the maximum leaf area index at 90 DAS. Similar trends have also been reported in earlier studies. (Xue *et al.*, 2021), (Nie *et al.*, 2017) [15, 25].

At different phases of growth, the interaction impact was shown to be substantial; nevertheless, in the majority of situations, the results were found to be comparable.

Table 1: Effect of sowing time, nitrogen, and zinc management on plant height (cm) at 30, 60, 90 DAS and harvesting stage in wheat

Treatments	Plant height			
	30 DAS	60 DAS	90 DAS	At harvest
Sowing time				
D1	20.76	57.39	81.95	93.99
D2	18.31	52.02	74.75	85.58
SEm ±	0.18	0.49	0.68	0.40
LSD (P=0.05)	0.59	1.72	2.33	1.38
Nitrogen management				
N ₁	19.81	55.03	79.52	86.67
N ₂	19.26	54.38	77.18	92.9
SEm ±	0.18	0.49	0.68	0.40
LSD (P = 0.05)	NS	NS	NS	1.38
Zinc management				
Z ₁	18.79	52.74	71.79	85.8
Z ₂	20.01	57.32	79.94	88.98
Z ₃	19.7	54.44	83.53	98.07
Z ₄	19.64	54.32	78.14	86.3
SEm ±	0.22	0.54	0.69	0.60
LSD (P = 0.05)	0.63	1.59	1.99	1.76

Table 2: Effect of sowing time, nitrogen, and zinc management on tiller count in nos (m⁻¹) at 30, 60, 90 DAS and harvesting stage in wheat

Treatments	Tiller count (m ⁻¹)			
	30 DAS	60 DAS	90 DAS	At harvest
Sowing time				
D1	76.61	108.23	91.59	97.38
D2	68.5	98.93	83.35	88.35
SEm ±	0.95	0.94	1.28	1.13
LSD (P=0.05)	3.25	3.26	4.39	3.91
Nitrogen management				
N ₁	72.96	104.6	87.84	92.36
N ₂	72.15	102.56	87.1	93.37
SEm ±	0.95	0.94	1.28	1.13
LSD (P = 0.05)	NS	NS	NS	NS
Zinc management				
Z ₁	68.19	98.16	81.41	87.17
Z ₂	78.68	109.82	85	95.79
Z ₃	72.57	107.53	98.65	96.51
Z ₄	70.79	98.81	84.83	91.99
SEm ±	1.56	1.35	1.29	1.08
LSD (P = 0.05)	4.54	3.94	3.74	3.17

Table 3: Effect of sowing time, nitrogen, and zinc management on shoot dry matter accumulation (SDMA) in (g m⁻¹) at 30, 60, 90 DAS and harvesting stage in wheat

Treatments	Dry matter accumulation(g m ⁻¹)			
	30 DAS	60 DAS	90 DAS	At harvest
Sowing time				
D1	6.99	34.51	173	204.7
D2	5.59	32.73	152.4	191.9
SEm ±	0.49	0.46	2.71	0.69
LSD (P =0.05)	1.16	1.11	8.87	1.91
Nitrogen management				
N ₁	5.98	33.64	166.5	189.7
N ₂	6.59	33.6	158.9	206.8
SEm ±	0.49	0.46	2.71	0.69
LSD (P = 0.05)	1.24	1.21	8.20	1.91
Zinc management				
Z ₁	5.29	32.61	146.5	179.4
Z ₂	7.48	34.77	168.9	203.9
Z ₃	5.84	33.2	178.7	214
Z ₄	6.54	33.9	156.9	196
SEm ±	0.72	0.57	2.28	2.47
LSD (P = 0.05)	1.70	1.29	6.29	6.89

Table 4: Effect of sowing time, nitrogen, and zinc management on Leaf area index (LAI) at 30, 60, and 90 DAS in wheat

Treatments	Leaf area index (LAI)		
	30 DAS	60 DAS	90 DAS
Sowing time			
D1	0.79	3.06	3.45
D2	0.59	2.30	2.84
SEm ±	0.01	0.10	0.07
LSD (P =0.05)	0.03	0.36	0.22
Nitrogen management			
N ₁	0.70	2.85	3.22
N ₂	0.68	2.51	3.06
SEm ±	0.01	0.10	0.07
LSD (P = 0.05)	NS	NS	NS
Zinc management			
Z ₁	0.61	2.22	2.79
Z ₂	0.74	3.14	3.33
Z ₃	0.71	2.97	3.32
Z ₄	0.71	2.38	3.14
SEm ±	0.03	0.09	0.06
LSD (P = 0.05)	0.10	0.29	0.14

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