Plant Archives Vol. 25, Supplement 2, 2025 pp.333-339 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org
DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2025.v25.supplement-2.042

PERFORMANCE OF WHEAT (*TRITICUM AESTIVUM* L.) AS INFLUENCED BY ZINC APPLICATION IN COMBINATION WITH PRIMARY NUTRIENTS IN MID-HILLS OF HIMACHAL PRADESH INDIA

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(Date of Receiving : 28-02-2025; Date of Acceptance : 07-05-2025)

ABSTRACT

A field experiment was conducted during the *Rabi* season of 2022-23 at Chamelti Agriculture Farm, Shoolini University of Biotechnology and Management Sciences, Solan (H.P). Based on the experimental findings, it can be concluded that application of 100% RDF + 20 kg ha^{-1} $ZnSO_4$ resulted in the highest growth parameters (plant height, number of tillers, dry matter accumulation and crop growth rate), yield attributes (number of effective tillers, number of grains per spike, spike length and test weight), and yield (grain yield, straw yield, biological yield and harvest index). Furthermore, it was increased gross returns, net returns and benefit-cost (B:C) ratio. Therefore, treatments are getting 100% RDF +10 kg ha^{-1} soil and 0.5% foliar application ($ZnSO_4$) (T_{10}) and 100% RDNP + 20 kg ha^{-1} $ZnSO_4$ (T_7) performed on par with T_6. While, the lowest growth, yield and economic parameters were recorded under Control (T_1).
***Keywords*: Wheat, Zinc application, Primary nutrients, plant height, number of tillers, dry matter accumulation, crop growth rate

Introduction

Wheat, an important cereal crop, is referred to be a staple food since it is widely consumed by humans and animals around the world. Wheat is known as the "King of cereals" due to its remarkable tolerance to many climates and capacity to grow under varying agro-climatic conditions, it has become a cornerstone of world agriculture. Wheat is the wonderful source of carbohydrate and energy, and it has more protein than rice. It is also rich in vital vitamins such as niacin and thiamine, which contribute greatly to nutritional security (Shewry and Hey, 2015; Ali *et al.*, 2022). Wheat is grown on an estimated 220.29 million hectares worldwide, yielding roughly 780.59 million tons at a production rate of 3390 kg ha^{-1} (Mundu *et al.*, 2024). India is the world's second-largest producer, trailing only China, with 316.15 lakh hectares under cultivation, 109.52 million tons produced, and an average yield of 3464 kg ha^{-1} (Anonymous, 2022-23a). India, a major wheat-growing country, has been divided into six distinct agroclimatic zones for optimal wheat production. Wheat is the most important *Rabi* season cereal crop, in the state of Himachal Pradesh, where it is grown over an area of 319.47 thousand hectares, giving a total production of 609.31 thousand metric tonnes with an average productivity of around 1907.22 (Anonymous 2022-23b). Despite significant progress in wheat production in recent years, India continues face problems due to its unusually low wheat yield. The intensive cultivation procedures frequently utilized in wheat production have produced major concerns, including soil carbon depletion, nitrogen loss, and low nutrient utilization efficiency (Thammaiah *et al.*, 2023; Parihar *et al.*, 2019; Das *et al.*, 2020). Fertilizer is an essential component in crop production, as crops require both major and micronutrients in adequate amounts to produce higher yields. The use of macro and micronutrients is critical for addressing these issues. To guarantee sustainable and effective crop production, these nutrients must be administered at the appropriate time, place, amount, and source (Ali *et al.*, 2014).

Nitrogen is one of the most yield limiting nutrients in crop growth across all agro-ecological regions (Allart *et al.*, 2023). Nitrogen deficiency affects both the physiological and metabolic processes of plants, influencing their overall growth, as it is vital component of chlorophyll (Bhardwaj *et al.*, 2021). The chlorophyll content of plants is directly linked to the concentration of nitrogen in the plant and leaves. Additionally, nitrogen is essential for the vegetative growth of plants (Kumar *et al.,* 2018). In recent years, the application of nitrogen has increased significantly and is projected to reach 180 million tons by 2030. However, cropping system dominated by cereals exhibit a low nitrogen use efficiency (NUE), ranging from 40% to 60%. Therefore, the judicious use of nitrogen is critical to realizing the full production of crops while minimizing environmental impacts (Chaudhary *et al.*, 2022). After nitrogen, phosphorus is an essential nutrient for crop production. It plays a crucial role in plant metabolism and serves a structural function in key molecules such as nucleic acids and proteins. Phosphorus is vital for energy transfer, respiration, glycolysis, carbohydrate metabolism, redox reactions, and enzyme activation and inactivation, synthesis and stability, as well as nitrogen fixation (Paramesh *et al.*, 2020; Moustakas *et al.*, 2020). During the initial developmental stages of a plant, phosphorus is particularly indispensable. In wheat, the average phosphorus uptake is about 3.8 kg P per ton of grains. However, the recovery of phosphorus from fertilizer by wheat is relatively low, with only 15-20% of the applied phosphorus being utilized by the crop. The remaining phosphorus often becomes fixed in the soil as insoluble fractions. On the other hand, potassium is absorbed by plants in larger quantities than any other and plays a vital role in improving grain quality. Potassium is essential for plants in plant survival, carbohydrate and protein synthesis, and cell development (Singh *et al.*, 2019; Sharma *et al.*, 2022). However, in many developing countries, the improper and imbalance use of fertilizer has become common. Nitrogen fertilizer is often prioritized, while potassium fertilizer is frequently neglected, leading to continuous potassium depletion in the soil. To achieve better crop productions and address fertilizer imbalances, it is imperative to apply fertilizer in the appropriate proportions based on crop requirements.

Micronutrient deficiencies affect approximately 75% of the global population, with insufficient Zinc intake leading to health issues such as anemia and weakened immune systems (Cakmak *et al.*, 2010). These problems impact around 40% of women and children worldwide. Zinc is also one of the most crucial micronutrients for plant growth, absorbed by roots in the form of Zn^{2+}. It plays a significant role in plant metabolism (Singh *et al.,* 2020), and its deficiency can disrupt various mechanism essential for plant development. Zinc is vital for activating plant enzymatic systems, protein synthesis, photosynthesis, and the reproduction of genetic material (DNA) through cell division. However, in India, nearly half of the soils are deficient in zinc, highlighting the need to enhance soil Zinc content. This deficiency can be addressed through Zinc fertilization, which involves using various sources such as chelated zinc and naturally occurring organic complexes like polymer-coated zinc. These practices ensure efficient zinc availability to plants, supporting healthy growth and improving overall crop productivity (Biswas *et al.*, 2015).

To treat macro and micro nutrient deficiencies, several agronomic measures must be used to increase the concentration and bioavailability of these nutrients in grains. This strategy not only improves human nutrition, but also ensures that plants meet their nutrient requirements efficiently. Recognizing the importance of nutrients, this study was conducted to evaluate the effects of foliar and soil application of zinc, in conjunction with other nutrients, on wheat growth and yield. Such interventions attempt to improve nutrient utilization efficiency and agricultural output which is also contributing to better nutritional outcomes for humans.

Materials and Methods

The present study was conducted during the *Rabi* season of 2022-23 at Agriculture farm Chamelti, MS Swaminathan school of Agriculture, Shoolini University of Biotechnology and Management Sciences, Solan (H.P). Meteorological data were recorded during the experimentation period (November to May) 2022-23, based on observations collected from the automatic weather station at Shoolini University of Biotechnology and Management Sciences, Solan (H.P.). The maximum temperature of 25^{o}C was recorded in the last week of October, while the minimum temperature of 0^0 C, and was observed in the third week of December. The maximum relative humidity of 85% occurred in the last week of January, whereas the minimum relative humidity of 38.2% was recorded in the third week of November. The total rainfall was received during the season was 26.6 mm. The variety PBW-677 was tested in the experimentation. The nutrients such as Nitrogen, Phosphorus, Potassium and Zinc were supplied by using the Urea, DAP, MOP and Zinc sulphate (mono zinc), respectively. The experiment followed a Randomized block Design (RBD) with 10 treatments and 3 replications. The treatments details were: T_1- Control, T_2- 50% RDN, T_3- 50% RDF + 20 kg/ha $ZnSO_4$, T_4- 75% RDF + 20 kg ha^{-1} $ZnSO_4$, T_5- 100% RDN + 20 kg ha^{-1} $ZnSO_4$, T_6- 100% RDF + 20 kg ha^{-1} $ZnSO_4$, T_7- 100% RDNP + 20 kg ha^{-1} $ZnSO_4$, T_8- 50% RDF + Foliar spray (0.5% $ZnSO_4$), T_9- 75% RDF + Foliar spray (0.5% $ZnSO_4$), T_{10}- 100% RDF +10 kg ha^{-1} soil and 0.5% Foliar application ($ZnSO_4$). RDF refers to a recommended dose of fertiliser, applied at a ratio of 120:60:40 (N: P: K). Full dose of phosphorus, potassium and half dose of nitrogen was applied as a basal (at the time of final field preparation) and remaining half nitrogen was applied in to two equal splits at tillering and spike initiation stage, respectively. Zinc fertilizer was applied to the soil along with 25% of the nitrogen at tillering stage. Foliar zinc application was conducted at the spike initiation stage. Growth parameters such as plant height (cm), number of tiller m^{-1} row length and dry matter accumulation were measured from the five tagged plant in each treatment and average value was computed to take a final observation. The crop growth rate was calculated by using following formula.

$$CGR = \frac{W_2 - W_1}{t_2 - t_1} g\ m^1\ row\ length\ day^1$$

Where,

W_1 and W_2 are plant dry weight at time t_1 and t_2, respectively

Results and Discussion

Effect on growth

The application of zinc alongside of macronutrients showed significant improvements in the growth characteristics of wheat. The maximum plant height (100 cm), dry matter accumulation (225.50 g m^{-1} row length), crop growth rate (0.212 – 0.525 g m^{-1} row length day^{-1}), and the number of tillers (45.3-84.3 m^{-1} row length) were recorded with the application of 100% RDF + 20 kg ha^{-1} $ZnSO_4$ (T_6) which is being exhibited statistically *at par* with 100% RDF + 10 kg ha^{-1} soil application and 0.5% foliar application of $ZnSO_4$ (T_{10}) and 100% RDNP + 20 Kg ha^{-1} $ZnSO_4$ (T_7) Table 1. The increase in plant height might be attributed due to improve in availability of major nutrients facilitated by zinc fertilization, which enhances metabolic and enzymatic activities of the plants this likely promoted cell division and elongation. Additionally, the combined application of nitrogen and $ZnSO_4$ enhanced chlorophyll synthesis, a critical factor in height increment. Zinc also plays a vital role in crop growth rate through its involvement in photosynthesis, respiration, nitrogen metabolism, and protein synthesis. It facilitates faster dry matter accumulation per unit leaf area per unit time, reducing the senescence of leaves and the death of tillers in wheat. This ultimately leads to increased dry matter accumulation and better overall growth. These results were corroborated with the findings of (Yadav *et al.*, 2018; Shalini *et al.*, 2020).

Effect on yield attributes and yield

Among all the treatments, the maximum yield attributing characters were observed with the application of 100% RDF + 20 Kg ha^{-1} $ZnSO_4$ (T_6). These included: Number of effective tillers (72 tillers m^{-1} row length), Number of grains $spike^{-1}$ (62), Spike length, Test weight (35.00 g). The results for T_6 were statistically at par with 100% RDF + 10 Kg ha^{-1} soil application and 0.5% foliar application of $ZnSO_4$ (T_{10}) and 100% RDNP + 20 Kg ha^{-1} $ZnSO_4$ (T_7) Table 2. The increase in grain yield with higher nitrogen doses can be attributed to improved photosynthate accumulation and translocation from source to sink. Additionally, zinc contributes to the initiation of primordia for reproductive parts and enhances photosynthesis, carbohydrate transformation, and seed development, resulting in bolder grains and improved test weight. The results are supported by the Findings of (Prajapati *et al.*, 2022; Mattas *et al.*, 2011; Sharma *et al.*, 2016; Tiwari *et al.*, 2023)

The highest Grain yield (48.79 q ha^{-1}), Straw yield (70.87 q ha^{-1}), Biological yield (119.67 q ha^{-1}) and Harvest Index (40.78%) were achieved with the application of 100% RDF + 20 Kg ha^{-1} $ZnSO_4$. Data is presented in Table No. 3. These results were statistically at par with T_{10} and T_7. The increase in biomass and straw yields with higher nitrogen levels reflects nitrogen's critical role in dry matter production and organ development (Sun *et al.*, 2020). Dry matter, being the net product of photosynthesis, contributes significantly to biomass and straw production. Zinc role in initiating reproductive primordia and synthesizing indole acetic acid (IAA) likely contributed to the better development of yield-attributing traits (Zhang *et al.*, 2020). Furthermore, the increase in grains $spike^{-1}$ due to potassium application underscores its positive impact on physiological processes like photosynthesis and nutrient transport. The higher grain yield can be attributed to enhance growth and yield components due to balanced fertilization. The greater availability of metabolites and nutrients to developing reproductive structures likely contributed to the observed increases in yield attributing characters, ultimately improving overall crop yield. Similar results have been reported by (Kachroo and Rajdan, 2006; Yadav *et al.*, 2018; Khatik *et al.*, 2021; Kakraliya *et al.*, 2018).

Economic studies

The cost of cultivation varied significantly across treatments, with the lowest cost (Rs 31,930 ha^{-1}) recorded for crop grown without nutrient application and the highest (Rs 40,613 ha^{-1}) for those grown with 100% RDF + 20 kg ha^{-1} $ZnSO_4$ (T_6. The lower cultivation cost for the control treatment was due to savings on fertilizer expenses and reduced harvesting costs. The treatment 100% RDF + 20 kg ha^{-1} $ZnSO_4$ (T_6) generated the highest gross returns of RS 1,24,948 ha^{-1}, closely followed by 100% RDF + 10 kg ha^{-1} soil application and 0.5% foliar application of $ZnSO_4$ (T_{10}) and 100% RDNP + 20 kg ha^{-1} $ZnSO_4$ (T_7). Data is presented in table No. 4. The higher monetary returns in these treatments were primarily due to the increased crop yield, combined with a nearly similar cost of cultivation, leading to greater gross and net returns. The maximum Benefit-Cost (B:C) ratio of 2.08 was observed for treatments T_6 followed by T_{10}, and T_7, may be due to the advantages of balanced nutrient application, as it enhances yield and profitability. In contrast, the control treatment, with no fertilizer input, resulted in significantly lower returns, reflecting its minimal yield and economic viability. Similar results were reported by (Vijaykumar *et al.*, 2019; Borse *et al.*, 2022).

Conclusion

Based on the experimental findings, it can be concluded that the application of 100% RDF + 20 kg ha^{-1} ZnSO4 (T_6) is beneficial for highest growth parameters (plant height, number of tillers and dry matter accumulation), improved yield attributes (number of effective tillers, number of grains $spike^{-1}$, spike length and test weight) and achieved highest yield (grain, straw, biological yield and harvest index). Additionally, this treatment demonstrated the most favorable economic performance by achieving maximum gross returns, net returns and benefit-cost ratio. The findings of experiment demonstrate that zinc use in conjunction with primary macro nutrients improved efficacy of combining balanced macronutrient and micronutrient application, particularly zinc, in improving crop growth, productivity and economic returns.

Table 1: Growth parameters of wheat as influenced by different nutrient management practices.

Treatments	Treatments Details	Plant height (cm)	No of tillers (m^{-1} row length)	Dry matter accumulation ($g\ m^{-1}$ row length)	Crop growth rate ($g\ m^{-1}$ row length day^{-1})
T_1	Control	45.3	45.3	91.14	0.212
T_2	50% RDF	56.3	52.7	137.55	0.320
T_3	50% RDF + 20 kg ha^{-1} $ZnSO_4$	57.3	57.7	147.13	0.343
T_4	75% RDF + 20 kg ha^{-1} $ZnSO_4$	66.7	69.7	173.66	0.404
T_5	100% RDN + 20 kg ha^{-1} $ZnSO_4$	76.0	75.3	181.46	0.423
T_6	100% RDF + 20 kg ha^{-1} $ZnSO_4$	100.0	84.3	225.50	0.525
T_7	100% RDNP + 20 kg ha^{-1} $ZnSO_4$	78.9	78.7	211.10	0.492
T_8	50% RDF + Foliar spray (0.5% $ZnSO_4$)	56.0	54.3	139.29	0.324
T_9	75% RDF + Foliar spray (0.5% $ZnSO_4$)	65.4	64.7	166.69	0.388
T_{10}	100% RDF +10 kg ha^{-1} soil and 0.5% Foliar application $ZnSO_4$	95.4	80.0	219.55	0.511
	SEm±	3.9	3.4	4.98	0.011
	CD (p=0.05)	11.3	9.8	14.40	0.033

Table 2: Yield attributes of wheat as influenced by different nutrient management practices.

Treatments	Treatments Details	Effective tillers (m^{-1} row length)	No of grains ($Spike^{-1}$)	Spike length (cm)	Test weight (g)
T_1	Control	36	24	9.3	33.80
T_2	50% RDF	43	33	10.7	33.93
T_3	50% RDF + 20 kg ha^{-1} $ZnSO_4$	50	40	11.9	33.97
T_4	75% RDF + 20 kg ha^{-1} $ZnSO_4$	60	47	13.1	34.67
T_5	100% RDN + 20 kg ha^{-1} $ZnSO_4$	61	53	13.8	33.47
T_6	100% RDF + 20 kg ha^{-1} $ZnSO_4$	72	62	16.1	35.00
T_7	100% RDNP + 20 kg ha^{-1} $ZnSO_4$	64	56	14.3	33.57
T_8	50% RDF + Foliar spray (0.5% $ZnSO_4$)	51	48	10.4	33.90
T_9	75% RDF + Foliar spray (0.5% $ZnSO_4$)	55	43	12.3	34.40
T_{10}	100% RDF +10 kg ha^{-1} soil and 0.5% Foliar application $ZnSO_4$	69	59	14.6	34.93
	SEm±	3.3	2.5	0.8	0.38
	CD (p=0.05)	9.5	7.3	2.3	1.09

Table 3: Yield of wheat as influenced by different nutrient management practices.

Treatments	Treatments Details	Yield (q ha^{-1})			Harvest Index (%)
		Grain	Straw	Biological	
T_1	Control	20.27	35.16	55.43	36.62
T_2	50% RDF	29.76	47.61	77.37	38.30
T_3	50% RDF + 20 kg ha^{-1} $ZnSO_4$	29.76	50.08	82.19	39.07
T_4	75% RDF + 20 kg ha^{-1} $ZnSO_4$	37.88	56.94	94.82	39.95
T_5	100% RDN + 20 kg ha^{-1} $ZnSO_4$	38.65	60.12	98.77	38.99
T_6	100% RDF + 20 kg ha^{-1} $ZnSO_4$	48.79	70.87	119.67	40.78
T_7	100% RDNP + 20 kg ha^{-1} $ZnSO_4$	45.41	67.69	113.10	40.15
T_8	50% RDF + Foliar spray (0.5% $ZnSO_4$)	30.05	48.17	78.22	38.43
T_9	75% RDF + Foliar spray (0.5% $ZnSO_4$)	35.94	55.70	91.64	39.20
T_{10}	100% RDF +10 kg ha^{-1} soil and 0.5% Foliar application $ZnSO_4$	47.54	69.83	117.36	40.49
	SEm±	2.66	3.79	6.39	0.48
	CD (p=0.05)	7.69	10.96	18.48	1.38

Table 4: Economics of wheat as influenced by different nutrient management practices

Treatments	Treatments Details	Gross returns (Rs. ha^{-1})	Cost of cultivation (Rs. $ha^{-1)}$	Net returns (Rs. ha^{-1})	B:C ratio
T_1	Control	53628	31930	21698	0.68
T_2	50% RDF	75399	35554	39845	1.12
T_3	50% RDF + 20 kg ha^{-1} $ZnSO_4$	75399	36996	46255	1.25
T_4	75% RDF + 20 kg ha^{-1} $ZnSO_4$	97584	38803	58781	1.51
T_5	100% RDN + 20 kg ha^{-1} $ZnSO_4$	100161	33531	66631	1.99
T_6	100% RDF + 20 kg ha^{-1} $ZnSO_4$	124948	40613	84335	2.08
T_7	100% RDNP + 20 kg ha^{-1} $ZnSO_4$	116810	38279	78531	2.05
T_8	50% RDF + Foliar spray (0.5% $ZnSO_4$)	78315	35914	42401	1.18
T_9	75% RDF + Foliar spray (0.5% $ZnSO_4$)	93075	37722	55354	1.47
T_{10}	100% RDF +10 kg ha^{-1} soil and 0.5% Foliar application $ZnSO_4$	121971	40252	81718	2.03
	SEm±	4129	-	4129	0.11
	CD (p=0.05)	11943	-	11943	0.33

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