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Nitrogen and zinc management in transplanted rice (*Oryza sativa* L.)

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Abstract
The present investigation entitled "Nitrogen and Zinc management in transplanted rice (*Oryza sativa* L.)" was carried out during *kharif* season 2024 at the Instructional Cum Research Farm, Barrister Thakur Chhedilal College of Agriculture and Research Station, Bilaspur (C.G.). The experiment was laid out in Randomized Block Design with three replications. The treatments consisted of seven nutrient management practices *viz.*, (T_1) Control 100% PK, (T_2) RDF (NPK 100:60:40 kg ha^{-1}), (T_3) 100% RDF + Zn + nano N foliar spray once at 20 DAT, (T_4) 100% PK + 75% N + Zn + nano N foliar spray twice at 20 & 40 DAT, (T_5) 100% PK + 75% N + Zn + nano N foliar spray thrice at 20, 40 & 60 DAT, (T_6) 100% PK + 50% N + Zn + nano N foliar spray twice at 20 & 40 DAT and (T_7) 100% PK + 50% N + Zn + nano N foliar spray thrice at 20, 40 & 60 DAT. The results showed that growth parameters, *viz.*, plant height, number of tillers and yield attributes *viz.*, panicle length (26.23 cm), number of grain panicle^{-1} (155.04), number of panicles hill^{-1} (10.74) and test weight (24.16 g) was found to be higher under treatment T_5 - 100% PK + 75% N + Zn + nano N foliar spray thrice at 20, 40 & 60 DAT, followed by T_4 - 100% PK + 75% N + Zn + nano N foliar spray twice at 20 & 40 DAT. The yield parameters like grain yield and straw yield, recorded maximum yield (53.43 q ha^{-1}) under T_5 - 100% PK + 75% N + Zn + nano N foliar spray thrice at 20, 40 & 60 DAT, followed by T_4 (50.81 q ha^{-1}), (T_3) (48.06 q ha^{-1}) and (T_2) (46.87 q ha^{-1}). The economic parameters like gross returns, net returns and B:C ratio was significantly superior under treatment T_5 - 100% PK + 75% N + Zn + nano N foliar spray thrice at 20, 40 & 60 DAT highest gross return (137403.67 ₹ ha^{-1}) and this treatment also gave highest net return (93595.14 ₹ ha^{-1}) and B:C ratio 2.14. However, lowest gross return (69409.37 ₹ ha^{-1}) lowest net return (31814.04 ₹ ha^{-1}) and lowest B:C ratio (0.85) was obtained under treatment T_1 - Control 100% PK.

Keywords: Rice, Nano N, foliar spray, zinc, economics and yield

Introduction
Rice (*Oryza sativa* L.), a vital cereal crop from the Poaceae family, plays a significant role in the global food system. Nearly half of the world's population relies on rice as their main energy source. It is the staple food for much of East and Southeast Asia, where it contributes around 70% of daily caloric intake. In regions like Asia and Africa home to many of the world's poorest and most undernourished populations rice is often the most accessible and affordable source of nutrition, making it a critical food crop worldwide. Its importance extends beyond nutrition; rice is also deeply tied to regional peace, economic growth, job creation, and global food security. As it is the only cereal commonly consumed whole after cooking, quality characteristics are particularly important. Nutritionally, rice consists of about 80% carbohydrates, 7–8% protein, 3% fat, and 3% fiber (Chaturvedi, 2005) [6]. It also provides essential micronutrients such as vitamin B_1 (thiamine), B_2 (riboflavin), and B_3 (niacin), along with amino acids like glutamic acid and aspartic acid (FAO, 2004). Rice straw, a byproduct of cultivation, has various uses, including animal fodder, mushroom cultivation, and in small-scale industries for making ropes, mats, poultry bedding, paper pulp, alcohol, and thatching materials. Globally, rice production reached 503.8 million tonnes in 2019–20, increasing to 518.1 million tonnes in 2020–21 (FAO, 2022). In India, rice production during 2021–22 was estimated at

127.93 million tonnes 11.49 million tonnes more than the previous five-year average of 116.44 million tonnes (Anonymous, 2022) [2, 3]. In India, Chhattisgarh is known as the "Rice Bowl of India" due to rice's dominance in both the state's economy and culture. In 2019–20, the state had a rice-growing area of 3,876.13 thousand hectares with an average productivity of 3,002 kg ha^{-1}. In 2020–21, the area increased to 3,903.92 thousand hectares and productivity improved to 3,438 kg ha^{-1} (Anonymous, 2024) [4].

Fertilizers play a vital role in enhancing both the quality and quantity of agricultural produce, particularly with the advent of high-yielding crop varieties that are highly responsive to fertilizer application. Rice, like many other crops, relies heavily on inorganic nutrient inputs. Its productivity is largely influenced by soil conditions and, more importantly, the availability of key nutrients such as nitrogen, phosphorus, potassium, sulphur, and zinc (Masum *et al*., 2013). Among these, nitrogen stands out as the most critical nutrient for rice cultivation. Nitrogen is fundamental in the formation of chlorophyll, which is essential for photosynthesis. It is a primary nutrient responsible for giving plants their lush green color and supporting vigorous vegetative growth. In rice, nitrogen is particularly important during the early vegetative stage and panicle initiation phase. Nitrogen application during the early growth stage encourages tillering, thereby increasing the potential yield. When applied at the panicle initiation or early booting stage, nitrogen enhances the size and weight of grains per panicle. Additionally, nitrogen is a key element in various enzymes and proteins that regulate plant development (Khaled *et al*., 2021) [14]. Therefore, nitrogen is indispensable for the proper growth and metabolic functions of rice. Research also shows that an optimal nitrogen supply positively affects key yield components such as panicle length, dry matter accumulation, and the number of panicles per square meter (Sheoran *et al*., 2021) [26].

Nano urea has been introduced with the goal of reducing traditional urea usage by up to 50%. Its dosage depends on several factors such as the crop's nitrogen demand, water requirement, and canopy development. Typically, it is applied at a concentration of 2.0–4.0 ml per litre of water. Application is most effective during key growth stages when the crop canopy is sufficiently developed to absorb nutrients efficiently through foliar feeding. A 500 ml bottle of Nano urea contains 40,000 mg/L of nitrogen, equivalent to the nitrogen content in one conventional bag of urea. With an absorption efficiency exceeding 80%, Nano urea meets the nitrogen requirements of crops more effectively and in smaller quantities than traditional urea. Its nanoscale particles, with a high surface area-to-volume ratio, facilitate a controlled release of nutrients, thereby reducing nutrient loss through leaching and improving efficiency (Lahari, 2021) [15]. Unlike conventional fertilizers, nano fertilizers offer a slow and steady nutrient release. They can be applied either as a foliar spray or directly to the soil for root absorption (Jassim *et al*., 2020) [12]. Consequently, using Nano urea especially through foliar application can enhance nitrogen use efficiency, improve crop yield, and reduce input costs. Despite its potential benefits, research on Nano urea application in rice remains limited.

Materials and Methods

During the *kharif* season of 2024, the experiment was carried out at the Agriculture Research Cum Instructional Farm, Barrister Thakur Chhedilal College of Agriculture and Research Bilaspur (C.G.). The location of the Bilaspur district is latitude 22.09˚N and longitude 82.15˚E. This area is classified as India's Eastern Plateau and Hill Region (Agro-climatic zone VII). The state of Chhattisgarh is divided into three agro-climatic zones; Bilaspur is located in the state's plains zone. The experiment was laid out in Randomized Block Design with three replications. The treatments consisted of seven nutrient management practices *viz*., (T_1) Control 100% PK, (T_2) RDF (NPK 100:60:40 kg ha^{-1}), (T_3) 100% RDF + Zn + nano N foliar spray once at 20 DAT, (T_4) 100% PK + 75% N + Zn + nano N foliar spray twice at 20 & 40 DAT, (T_5) 100% PK + 75% N + Zn + nano N foliar spray thrice at 20, 40 & 60 DAT, (T_6) 100% PK + 50% N + Zn + nano N foliar spray twice at 20 & 40 DAT and (T_7) 100% PK + 50% N + Zn + nano N foliar spray thrice at 20, 40 & 60 DAT. Observations on plant height, number of tillers, dry matter accumulation and number of panicles, panicle length and number of grains, test weight, grain yield and straw yield of rice crop were recorded at harvest and statistically analyzed. Economics of rice as a net return, gross return and benefit cost ratio were also worked out.

Results and Discussion

Growth parameters of rice recorded at 30, 60, 90 DAT and at harvest significant relationship among the treatments has been obtained. Results revealed that under (T_5) 100% PK + 75% N + Zn + nano N foliar spray thrice at 20, 40 & 60 DAT, the tallest plant height and highest dry matter accumulation were recorded. This treatment was being statistically at par with (T_4) 100% PK + 75% N + Zn + nano N foliar spray twice at 20 & 40 DAT, (T_3) 100% RDF + Zn + nano N foliar spray once at 20 DAT and (T_2) RDF (NPK 100:60:40 kg ha^{-1}). The smallest plant height and minimum dry matter accumulation were recorded under (T_1) Control 100% PK. The crop growth rate (CGR) and relative growth rate (RGR) of rice was calculated for the intervals of 0–30, 30–60, 60–90 DAT and from 90 DAT to harvest. The highest CGR and RGR were recorded under treatment (T_5) 100% PK + 75% N + Zn + nano N foliar spray thrice at 20, 40 & 60 DAT. This was followed by (T_4) 100% PK + 75% N + Zn + nano N foliar spray twice at 20 & 40 DAT, (T_3) 100% RDF + Zn + nano N foliar spray once at 20 DAT and (T_2) RDF (NPK 100:60:40 kg ha^{-1}). The lowest CGR and RGR were consistently observed in the Control 100% PK (T_1) across all growth periods.

Yield parameters of rice *viz*., number of tillers $hill^{-1}$ at 30, 60, 90 DAT and at harvest, number of panicle and number of grains was recorded under after harvest. The statistically significant highest under the treatment (T_5) 100% PK + 75% N + Zn + nano N foliar spray thrice at 20, 40 & 60 DAT. This treatment was statistically at par with (T_4) 100% PK + 75% N + Zn + nano N foliar spray twice at 20 & 40 DAT, (T_3) 100% RDF + Zn + nano N foliar spray once at 20 DAT and (T_2) RDF (NPK 100:60:40 kg ha^{-1}). The lowest were recorded in the (T_1) Control 100% PK. The results indicated that the longest panicle length was observed under treatment (T_5) 100% PK + 75% N + Zn + nano N foliar spray thrice at 20, 40 & 60 DAT, this was followed closely by (T_4) 100% PK + 75% N + Zn + nano N foliar spray twice at 20 & 40 DAT, (T_3) 100% RDF + Zn + nano N foliar spray once at 20 DAT and (T_2) RDF (NPK 100:60:40 kg ha^{-1}). The nutrient sources are significantly affected the grain and straw yield. The significantly the highest grain and straw yield of rice was recorded under (T_5) 100% PK + 75% N + Zn + nano N foliar spray thrice at 20, 40 & 60 DAT, this treatment was being statistically significant at par with (T_4) 100% PK + 75% N + Zn + nano N foliar spray twice at 20 & 40 DAT, (T_3) 100% RDF + Zn + nano N foliar spray once at 20 DAT and (T_2) RDF (NPK 100:60:40 kg ha^{-1}). The optimal course of action was then (T_7) 100% PK + 50% N + Zn + nano N foliar spray thrice at 20, 40 & 60 DAT. This treatment was statistically similar to (T_6) 100% PK + 50% N + Zn + nano N foliar spray twice at 20 & 40 DAT. Under (T_1) Control 100% PK, the lowest grain yield of rice was measured. The highest (though statistically significant) harvest index was recorded under (T_5) 100% PK + 75% N + Zn + nano N foliar spray thrice at 20, 40 & 60 DAT. The highest cost of cultivation (43808.53 ₹ ha^{-1}) was recorded under (T_5) 100% PK + 75% N + Zn + nano N foliar spray thrice at 20, 40 & 60 DAT due to higher cost involved in labour wages, followed by the treatment (T_7) 100% PK + 50% N + Zn + nano N foliar spray thrice at 20, 40 & 60 DAT. The highest gross return (137403.67 ₹ ha^{-1}) and net return (93595.14 ₹ ha^{-1}) were obtained (T_5) 100% PK + 75% N + Zn + nano N foliar spray thrice at 20, 40 & 60 DAT, followed by the treatment of (T_4) 100% PK + 75% N + Zn + nano N foliar spray twice at 20 & 40 DAT. The highest benefit: cost ratio (2.14) recorded under the treatment of (T_5) 100% PK + 75% N + Zn + nano N foliar spray thrice at 20, 40 & 60 DAT. However, minimum gross return, net returns and benefit: cost ratio was obtained under Control 100% PK (T_1).

Table 1: Effect of Nitrogen and Zinc on plant height of transplanted rice (*Oryza savita* L.)

Treatment No.	Treatment details	Plant height (cm)			
		30 DAT	60 DAT	90 DAT	At harvest
T_1	Control 100% PK	36.73	63.54	80.07	78.60
T_2	RDF (NPK 100:60:40 kg ha^{-1})	53.59	92.71	116.83	114.68
T_3	100% RDF + Zn + nano N foliar spray once at 20 DAT	54.29	93.92	118.35	116.18
T_4	100% PK + 75% N + Zn + nano N foliar spray twice at 20 & 40 DAT	55.42	95.88	120.82	118.60
T_5	100% PK + 75% N + Zn + nano N foliar spray thrice at 20, 40 & 60 DAT	57.43	99.35	125.20	122.90
T_6	100% PK + 50% N + Zn + nano N foliar spray twice at 20 & 40 DAT	47.12	81.52	102.72	100.84
T_7	100% PK + 50% N + Zn + nano N foliar spray thrice at 20, 40 & 60 DAT	48.34	83.63	105.38	103.45
S.Em (±)		1.56	2.84	3.55	3.34
CD (5%)		4.81	8.76	10.94	10.28

Table 2: Effect of Nitrogen and Zinc on number of tillers of transplanted rice (*Oryza savita* L.).

Treatment No.	Treatment details	Number of tillers ($hill^{-1}$)			
		30 DAT	60 DAT	90 DAT	At harvest
T_1	Control 100% PK	4.97	7.21	7.85	7.46
T_2	RDF (NPK 100:60:40 kg ha^{-1})	7.63	11.06	12.06	11.45
T_3	100% RDF + Zn + nano N foliar spray once at 20 DAT	7.74	11.22	12.23	11.61
T_4	100% PK + 75% N + Zn + nano N foliar spray twice at 20 & 40 DAT	7.89	11.44	12.47	11.84
T_5	100% PK + 75% N + Zn + nano N foliar spray thrice at 20, 40 & 60 DAT	8.14	11.80	12.86	12.21
T_6	100% PK + 50% N + Zn + nano N foliar spray twice at 20 & 40 DAT	6.33	9.18	10.00	9.50
T_7	100% PK + 50% N + Zn + nano N foliar spray thrice at 20, 40 & 60 DAT	6.36	9.22	10.07	9.54
S.Em (±)		0.37	0.56	0.63	0.59
CD (5%)		1.13	1.74	1.92	1.81

Table 3: Effect of Nitrogen and Zinc on dry matter accumulation of transplanted rice (*Oryza savita* L.).

Treatment No.	Treatment details	Dry matter accumulation (g $hill^{-1}$)			
		30 DAT	60 DAT	90 DAT	At harvest
T_1	Control 100% PK	6.62	32.77	69.05	73.55
T_2	RDF (NPK 100:60:40 kg ha^{-1})	10.92	54.05	113.90	121.32
T_3	100% RDF + Zn + nano N foliar spray once at 20 DAT	11.24	55.64	117.23	124.88
T_4	100% PK + 75% N + Zn + nano N foliar spray twice at 20 & 40 DAT	11.35	56.18	118.38	126.10
T_5	100% PK + 75% N + Zn + nano N foliar spray thrice at 20, 40 & 60 DAT	12.32	60.98	128.50	136.88
T_6	100% PK + 50% N + Zn + nano N foliar spray twice at 20 & 40 DAT	8.79	43.51	91.68	97.66
T_7	100% PK + 50% N + Zn + nano N foliar spray thrice at 20, 40 & 60 DAT	8.94	44.25	93.24	99.32
S.Em (±)		0.60	3.11	5.32	5.46
CD (5%)		1.85	9.56	16.42	16.83

Table 4: Effect of Nitrogen and Zinc on number of panicles, panicle length, number of grains and test weight of transplanted rice (*Oryza savita* L.).

1	Treatment details	Number of panicles ($hill^{-1}$)	Panicle length (cm)	Number of grains $panicle^{-1}$	Test weight (g)
T_1	Control 100% PK	6.56	12.22	116.26	22.97
T_2	RDF (NPK 100:60:40 kg ha^{-1})	10.07	23.37	147.76	23.75
T_3	100% RDF + Zn + nano N foliar spray once at 20 DAT	10.22	24.10	149.87	23.89
T_4	100% PK + 75% N + Zn + nano N foliar spray twice at 20 & 40 DAT	10.41	25.16	152.23	24.08
T_5	100% PK + 75% N + Zn + nano N foliar spray thrice at 20, 40 & 60 DAT	10.74	26.23	155.04	24.16
T_6	100% PK + 50% N + Zn + nano N foliar spray twice at 20 & 40 DAT	8.36	17.39	133.54	23.15
T_7	100% PK + 50% N + Zn + nano N foliar spray thrice at 20, 40 & 60 DAT	8.40	18.48	136.45	23.23
S.Em (±)		0.53	1.39	3.09	0.49
CD (5%)		1.62	4.28	9.52	NS

Table 5: Effect of Nitrogen and Zinc on grain yield, straw yield and harvest index of transplanted rice (*Oryza savita* L.).

Treatment No.	Treatment details	Grain yield (q ha^{-1})	Straw yield (q ha^{-1})	Harvest index (%)
T_1	Control 100% PK	26.73	30.43	46.76
T_2	RDF (NPK 100:60:40 kg ha^{-1})	46.87	48.91	48.94
T_3	100% RDF + Zn + nano N foliar spray once at 20 DAT	48.06	50.02	49.00
T_4	100% PK + 75% N + Zn + nano N foliar spray twice at 20 & 40 DAT	50.81	52.65	49.11
T_5	100% PK + 75% N + Zn + nano N foliar spray thrice at 20, 40 & 60 DAT	53.43	54.14	49.67
T_6	100% PK + 50% N + Zn + nano N foliar spray twice at 20 & 40 DAT	36.43	38.94	48.33
T_7	100% PK + 50% N + Zn + nano N foliar spray thrice at 20, 40 & 60 DAT	38.78	40.65	48.82
S.Em (±)		2.51	2.41	0.69
CD (5%)		7.75	7.43	2.13

Table 6: Effect of Nitrogen and Zinc on economics of transplanted rice (*Oryza savita* L.) cultivation.

Treatment No.	Treatment details	Cost of cultivation (₹ ha^{-1})	Gross return (₹ ha^{-1})	Net return (₹ ha^{-1})	B:C ratio
T_1	Control 100% PK	37595.33	69409.37	31814.04	0.85
T_2	RDF (NPK 100:60:40 kg ha^{-1})	39224.28	118448.03	79223.75	2.02
T_3	100% RDF + Zn + nano N foliar spray once at 20 DAT	41646.28	123539.69	81893.41	1.97
T_4	100% PK + 75% N + Zn + nano N foliar spray twice at 20 & 40 DAT	42566.53	133267.89	90701.36	2.13
T_5	100% PK + 75% N + Zn + nano N foliar spray thrice at 20, 40 & 60 DAT	43808.53	137403.67	93595.14	2.14
T_6	100% PK + 50% N + Zn + nano N foliar spray twice at 20 & 40 DAT	42244.77	94090.67	51845.90	1.23
T_7	100% PK + 50% N + Zn + nano N foliar spray thrice at 20, 40 & 60 DAT	43486.77	99999.82	56513.05	1.30

Conclusion

The results showed that growth parameters, *viz.*, plant height, number of tillers and yield attributes *viz*., panicle length (26.23 cm), number of grain panicle^{-1} (155.04), number of panicles hill^{-1} (10.74) and test weight (24.16 g) was found to be higher under treatment T_5 - 100% PK + 75% N + Zn + nano N foliar spray thrice at 20, 40 & 60 DAT. The yield parameters like grain yield and straw yield, recorded maximum yield (53.43 q ha^{-1}) under T_5 - 100% PK + 75% N + Zn + nano N foliar spray thrice at 20, 40 & 60 DAT, followed by T_4 (50.81 q ha^{-1}), T_3 (48.06 q ha^{-1}) and T_2 (46.87 q ha^{-1}). The economic parameters like gross returns, net returns and B:C ratio was significantly superior under treatment T_5 - 100% PK + 75% N + Zn + nano N foliar spray thrice at 20, 40 & 60 DAT highest gross return (137403.67 ₹ ha^{-1}) and this treatment also gave highest net return (93595.14 ₹ ha^{-1}) and B:C ratio 2.14. However, lowest gross return (69409.37 ₹ ha^{-1}) lowest net return (31814.04 ₹ ha^{-1}) and lowest B:C ratio (0.85) was obtained under treatment T_1 - Control 100% PK.

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