Indian Farming 75 (12): 37-40; December 2025

Zinc application boosts rice productivity in Tarai region of Uttarakhand

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Zinc is an essential micronutrient vital for plant growth, structural integrity of membranes, protein synthesis, and gene expression. Though required in small amounts, its deficiency severely limits crop productivity. In the Tarai region of Uttarakhand, rice yields improved significantly with Zn application, especially under balanced nutrient use. Treatments with 100% NPK+Zn and 100% NPK+FYM increased yields by 45% and 56% over 100% NPK, respectively, highlighting Zn as the most limiting factor. Integrated nutrient management sustained Zn availability over time. Thus, incorporating Zn in fertilizer schedules is critical for enhancing and maintaining rice productivity.

Keywords: Fertilizer, Mollisols, Plant nutrition, Rice, Uttarakhand, Zinc

RICE (*Oryza sativa* L.) remains the dietary backbone for more than 65% of India's population, shaping national food security, rural livelihoods, and the agricultural economy. In 2024–25, rice was cultivated on 51.42 million hectares, producing 149.07 million tonnes with an average productivity of 2900 kg/ha (DES 2025). Despite being a major rice-producing state, Uttarakhand records comparatively modest productivity, with rice covering ~4.5 lakh ha, producing ~5 lakh tonnes, and yielding ~2.5 t/ha. The lower yield levels, particularly in the fertile Tarai belt, underscore the significance of nutrient-related constraints in the production system. Among micronutrients, zinc (Zn) has emerged as a crucial limiting factor for rice productivity in this region. Zinc, though required in minute quantities, plays indispensable roles in enzyme activation, auxin synthesis, chlorophyll formation, and regulation of protein and nucleic acid metabolism. Its deficiency adversely impacts tillering, leaf area expansion, pollen viability, and ultimately grain yield. National Soil Fertility surveys revealed that 40–50% of Indian soils are zinc-deficient, with higher prevalence in intensively cultivated, sandy loam, calcareous, and alkaline soils.

Field studies in the Tarai region demonstrated that inclusion of Zn with balanced nutrient schedules significantly enhances rice yield. While 100% NPK fertilization improves productivity, addition of Zn (100% NPK + Zn) and integrated nutrient management (100% NPK + FYM) led to yield gains of 45% and 56%, respectively, over 100% NPK alone. This yield advantage is attributable to the fact that under control conditions, soil Zn levels often drop below the critical threshold, making it the most limiting nutrient for rice growth. Long-term experiments also highlight that Zn application not only corrects deficiency but also improves soil Zn reserves, while integrated nutrient management sustains its availability over years. Thus, strategic Zn fertilization, either through direct Zn amendments or in combination with organic manures, is pivotal to sustaining rice productivity in the Tarai region of Uttarakhand. Adoption of balanced and integrated nutrient management practices can help overcome widespread Zn deficiency, improve nutrient use efficiency, and ensure resilience of rice-based systems in the long run.

Role of Zinc (Zn)

The Zn ions have both beneficial and toxic effects on plant cells. It is inevitable in several plant metabolic processes like activation of carbonic anhydrase, protein synthesis, RNA polymerases, superoxide dismutase, alcohol dehydrogenase, lipid and nucleic acid, carbohydrate, metabolism. Also, as the Zn ions are integral parts of Zn finger family of transcription factors, thus, controls cell proliferation and differentiation. Besides these, Zn also plays important role in development and function of chloroplast. Thus, there is need of Zn by the cells for maintaining Zn homeostasis. The synthesis of chlorophyll in plants as well as reduction in growth and tolerance to stress happens during Zn deficiency. Zn is an important component of various enzymes that are responsible for driving many metabolic reactions in all crops. Growth and development would stop if specific enzymes were not present in plant tissue. Carbohydrate, protein, and chlorophyll formation is significantly reduced in Zn deficient plants. Therefore, a constant and continuous supply of Zn is needed for optimum growth and yield of plant.

Identification of Zn deficiency

Zn deficiency in India was first reported by Y.L. Nene in 1966 in paddy fields at Pantnagar, Uttarakhand. Dr. Nene is recognized as a pioneer in identifying Zn deficiency and developing strategies for its management. Globally, Zn deficiency in rice is known by various names: Khaira in India, Akagare Type II in Japan, Taya-Taya/Apulapaya in the Philippines, Hadda in Pakistan, and suffocating disease in Taiwan. Since its discovery, Zn deficiency has been acknowledged as a major nutritional constraint in rice-growing regions of Japan, USA, Brazil, and the Philippines. The total Zn content in soils depends on factors such as parent rock, weathering, organic matter, texture, and pH, with typical values ranging from 10–300 mg/kg (mean 50 mg/kg). Soils derived from basic rocks like basalt are richer in Zn, whereas those from acidic rocks such as granite and gneiss have lower Zn content. Light-textured soils generally have lower Zn than heavier soils. In rice, Zn deficiency impairs normal growth, with symptoms appearing within the first two to three weeks of the growing season. Early signs include yellowing of lower leaves, which progresses to bronze or brown colouration with a rusty appearance. These symptoms, commonly referred to as Khaira, usually appear on young or middle-aged leaves and should be confirmed through plant tissue analysis to distinguish from sunburn damage.

The main visible symptoms are (i) Leaf chlorosis occurs in which leaf colour changes from the normal green to pale green or yellow due to the reduced amount of chlorophyll in the leaf or oxidation of chlorophyll (ii) Necrotic spots on leaves occurs in areas of chlorosis due to death of plant tissue (iii) Bronzing of leaves reflects the development of reddish-brown spots/ lesions on leaves, and it is very typical in rice plants (iv) Rosetting of leaves occurs and consequently, the leaves close together in a cluster instead of being spread out between nodes in a healthy fruit trees (v) Stunting of plants as a result of reduced stem elongation and (vi) Dwarf leaves that is also called "little leaf". The malformed leaves are noticeably narrow and/or have wavy edges instead of straight edges.

Zinc deficiency in soils is directly linked to widespread human malnutrition, making its management crucial for food and nutritional security. Application of Zn to soil and crops offers a simple and effective approach to mitigate this deficiency. Although most crops tolerate high Zn without toxicity, cereals are sensitive, showing stunted growth, brown leaf spots, poor establishment, empty grains, delayed maturity, and yield loss. Deficiency symptoms often resemble S or Fe deficiency. Zn deficiency occurs in neutral to calcareous, sandy, saline–sodic, peat, highly weathered, and intensively cropped soils, especially under continuous flooding or high P and Si status.

Factors affecting Zn availability

Mollisols are among the most fertile soils, widely valued for their deep profiles, dark colour, and high organic matter content. Their excellent nutrient-holding capacity makes them highly productive for agriculture. The organic matter in mollisols not only enriches soil fertility but also influences Zn dynamics by serving as both a source and a chelating agent, thereby enhancing Zn availability for plant uptake. With a near-neutral to slightly acidic pH (around 6–7), mollisols generally

Symptoms of Zn deficiency in rice in LTFE in mollisols (Pantnagar, Uttarakhand) promote optimal Zn solubility and uptake. However, despite these advantages, Zn deficiencies may still occur in crops with high Zn demand or under intensive cultivation. In such cases, the application of Zn-containing fertilizers becomes necessary to maintain crop growth and yield. Sustainable practices such as crop rotation, cover cropping, and reduced tillage help preserve organic matter, ensuring long-term nutrient supply including Zn. Regular soil testing is therefore essential to monitor Zn status and guide appropriate nutrient management strategies, preventing hidden deficiencies in these otherwise fertile soils.

Impact of long-term Zn application on rice productivity

It has been observed that application of Zn in even imbalanced nutrient use found to be beneficial as in case of 100% N, 100% NP and 50% NPK. The balanced nutrient doses are performing well over the years. The 100% NPK+FYM gave maximum yield magnitude of 232% over control. The yield advantage due to 100% NPK+Zn and 100% NPK+FYM found to be at 45 and 56% over 100% NPK, respectively. It is because the soil status of Zn in control (0.57 mg/kg) has drastically gone down below critical level (0.57 mg/kg)and Zn found to be most limiting factor for rice yield as per Liebig's Law of Minimum. However whenever Zn is applied, the Zn status in soil is gradually enhanced and in INM, (100% NPK+FYM) it has been sustained very well. Thus as a result, use of Zn in fertilizer schedule plays a crucial role in enhancing and sustaining the rice productivity. Therefore, it is equally important to have an effective Zn management strategy to improve crop productivity and farm income.

Table 1. Impact of long-term manuring and fertilizer application on yield of rice and available Zn content in soil at Pantnagar (Mollisols)

Year	Control	100% N+Zn	100% NP+Zn	50% NPK+Zn	100% NPK	150% NPK	100% NPK + Zn	100% NPK + FYM	CD (0.05)
	Yield (q/ha)								
2020–21	17.00	34.20	42.00	33.80	34.20	33.23	48.80	53.12	2.01
2021–22	16.79	32.83	42.19	32.75	34.44	33.57	49.38	53.33	2.04
2022–23	15.42	32.76	42.45	33.32	33.10	33.24	48.25	51.68	2.11
2023–24	15.16	32.45	42.25	32.80	32.75	33.15	48.05	51.22	2.25
2024–25	14.12	31.24	42.18	32.04	32.45	32.84	47.65	51.46	-
Mean	15.70	32.70	42.21	32.94	33.39	33.21	48.43	52.16	2.10
Increase over control (%)	-	108.28	168.91	109.85	112.69	111.53	208.49	232.28	
	Available Zn (mg/kg) in soil								
2023–24	0.52	1.55	1.78	1.88	0.79	0.64	1.87	1.23	0.71

* Initial Zn content in soil = 2.7mg/kg; Critical level of available zinc in soil=0.6 mg/kg

Impact of S, Zn and FYM on rice yield under superimposition

In mollisols of Pantnagar, rice showed a significantly higher response to sulphur (S), zinc (Zn), and farmyard manure (FYM) under superimposed nutrient treatments. The application of 100% and 150% NPK in combination with S, Zn, and FYM resulted in maximum grain yield compared to treatments without S and Zn. Notably, sulphur application through S-containing fertilizers, such as single superphosphate (SSP), produced a marked positive effect. Zinc supplementation was critical, as treatments lacking Zn fertilizers exhibited Khaira disease, indicating its role in both yield enhancement and disease mitigation. Rice exhibited strong responses to nitrogen (N), S, Zn, and FYM, whereas responses to phosphorus (P) and potassium (K) were comparatively lower under superimposed treatments. Statistically, S and Zn applications showed at par response in 100% and 150% NPK treatments. Overall, the combined application of S, Zn, and FYM with NPK significantly enhanced rice productivity and crop health, emphasizing the importance of balanced nutrient management for achieving higher yields in Pantnagar Mollisols.

Efficiency of Zn in rice

The estimates on agronomic efficiency for individual nutrients i.e. N, P, K, and Zn was done for mollisols of Pantnagar. Upon application of unit amount of nutrient i.e. P application (36 kg grain/kg P)and Zn application (30 kg grain/kg Zn) recorded highest response compared to N and K. The study clearly depicted the beneficial effect of zinc on growth and yield of rice in this tarai areas as indicated through agronomic efficiency.

Strategies for mitigation of Zinc deficiency

The addition of Zn to starter fertilizer is the most economical and effective approach to correct Zn deficiency, ensuring nutrient availability during the year it is required. When starter fertilizers are not feasible, Zn should be applied through broadcasting and incorporation before planting. Soil application of Zn compounds remains the most common method, while foliar sprays are generally reserved for high-value crops such as fruits, vegetables, and grapes, as well as for field crops showing visible deficiency. Other options include seed treatment and root dipping of seedlings, particularly in rice, where dipping roots in 2–4% ZnO suspension

150% NPK+S+Zn

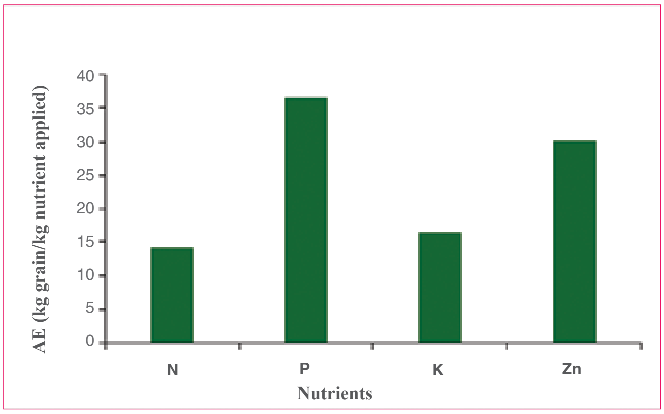
150% NPK+S+Zn+FYM

Impact of superimposition of Zn and S (in 150% NPK) on growth and yield of rice at Pantnagar

Table 2. Rice yields (q/ha) and magnitude of increase with application of S, Zn and FYM under superimposed treatments (2019–2024)

Treatment	2019–20	2020–21	2021–22	2022–23	2023–24	Pooled Mean	Increase in yield over control (%)	Increase due to application of nutrient
100% NPK								
-S	32.15	35.15	36.15	36.25	36.10	35.16		
+S	36.39	38.25	37.25	36.5	37.25	37.13	5.60	S
-S+Zn	39.23	47.23	45.23	44.8	46.05	44.51	26.59	Zn
+S+Zn	44.43	55.53	56.00	52.85	56.35	53.03	50.82	S and Zn
+S+Zn+FYM	50.52	56.52	55.52	53.92	55.45	54.39	54.69	S, Zn and FYM
CD (0.05)	1.32	2.16	3.01	2.16	2.81	-		
150% NPK								
-S	41.15	42.15	40.15	41.30	40.70	41.09		
+S	42.39	43.25	43.25	45.50	45.10	43.90	6.84	S
-S+Zn	45.23	48.23	46.23	46.48	47.15	46.66	13.56	Zn
+S+Zn	54.43	62.53	62.34	62.45	61.10	60.57	47.41	S and Zn
+S+Zn+FYM	57.00	67.52	65.52	66.24	65.25	64.31	56.51	S, Zn and FYM
CD (0.05)	2.23	2.34	2.16	2.45	3.10	-		

before transplanting is widely practiced. Fertigation has emerged as a modern technique for applying Zn fertilizers with NPK through irrigation water, providing uniform distribution, higher efficiency, and reduced risk of plant damage, especially in arid and semi-arid areas. Among commonly used Zn fertilizers, zinc sulphate monohydrate (36% Zn), zinc sulphate heptahydrate (22% Zn), zinc oxysulphate (20–50% Zn), basic zinc sulphate (55% Zn), ammoniated zinc sulphate (10% Zn), and zinc oxide (50–80% Zn) are widely adopted. Zn application rates of 10–25 kg $ZnSO_4$/ha are effective, with residual effects lasting 2–5 crop seasons, except in alkaline soils where annual application is necessary.



Agronomic efficiency (AE) for zinc in rice in mollisols of Pantnagar, Uttarakhand

SUMMARY

To address Zn deficiency in mollisols, several strategies are recommended. Regular soil testing is essential to monitor Zn levels and guide corrective measures. Zinc fertilization, using sources like zinc sulphate or chelates, helps alleviate deficiency, while foliar application ensures quick plant response. pH management around 6–7 improves Zn availability, though drastic pH adjustment is difficult. Crop rotation prevents continuous cultivation of Zn-sensitive crops, reducing deficiency risks. Additionally, optimizing phosphorus fertilization is important, as excess P can limit Zn uptake. Research indicates that most Zn sources, except granular ZnO, are equally effective in enhancing crop productivity and sustaining soil fertility.

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