Full Length Research Article

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Research Journal of Agricultural Sciences
Volume 17; Issue 04 (July–Aug 2026); pp 505–509

ISSN: 0976-1675 (P)
ISSN: 2249-4538 (E)

# Comparative Evaluation of Zinc Application Methods on the Growth, Yield and Grain Enrichment of Rice under Hill Condition of Nagaland

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Received: 17 May 2026; Revised accepted: 31 July 2026

## Abstract

A field experiment was conducted during the *kharif* seasons of 2023 and 2024 at the experimental farm of the Department of Agronomy, School of Agricultural Sciences, Nagaland University, to evaluate the effect of zinc application methods on growth, yield and grain zinc enrichment, under Nagaland soil condition. The experiment was laid out in a randomized block design with ten treatments and three replications. Treatments included control, recommended dose of fertilizer (RDF), seed priming with 2% $ZnSO_4$, soil application of $ZnSO_4$ at 15 kg $ha^{-1}$, and their combinations with foliar application of 0.5% $ZnSO_4$ at maximum tillering, panicle initiation, and grain-filling stages. Result of the experiment revealed that zinc significantly improved growth, yield and Zn content across the growing seasons of 2023 and 2024, as well as in the pooled analysis. The result indicates that zinc priming, along with foliar application at different growth stages enhanced plant population $m^{-2}$, grain yield and harvest index. However, CGR was more effective with the incorporation of soil zinc application + foliar application at different growth stages, which can be considered an effective way to enhance vegetative growth, and ultimately, the straw yield. Foliar application has also reportedly enhanced grain zinc concentration, specifically by soil application and additional spray at the grain filling stage.

***Key words***: *Oryza sativa* L., Agronomic bio-fortification, Zinc, Grain enrichment

Rice (*Oryza sativa* L.) is a major staple food consumed by more than half of the world's population, providing 43% of the caloric requirement and 20%-25% of agricultural income in many regions [1]. Approximately 90% of global rice production and consumption occurs in Asia, earning it the title "grain of life" [2] (Dhokne *et al*., 2025). In Nagaland, rice is cultivated over an area of 0.1965 million hectares, with a total production of 0.595 million metric tonnes [3]. Among essential nutrients, Zn is one of the most common forms of micronutrient malnutrition globally, and yet remains among the least well recognized [4]. While Nagaland shows lower Zn deficiency at around 18%**,** with most soils falling under the medium zinc category [5]. The deficiency of trace element especially Zn is a major concern as zinc plays an important role not only in the development of human immune system, physical growth, reproductive system and neurological behaviour but also in the cellular processes of all living organisms. Many plant enzymes including functional, structural, and regulatory enzymes, rely on zinc for their activity, including chlorophyll production and membrane integrity. Many studies have shown the effective intervention of agronomic biofortification in enriching plants and their consumable parts [6-8]. Zinc biofortification is also considered environmentally friendly, and cost-effective approach [9-10] mainly when applied through Nutri-priming or seed-priming in cereals. Though soil application is the most widely used method of Zn application. However, it is limited by different factors like pH, organic matter, redox potential of soil etc. [11]. Various independent studies have also shown that foliar fertilization is a more effective approach than soil-based fertilizers for the correction of zinc deficiency in rice [12-13]. In addition to these foliar applications of Zn provide nutrients to plants, revive the soil to an organic state, enhance plant growth, and reduce environmental pollution compared to soil-applied fertilizers [14].

Therefore, the present study was conducted to evaluate the effect of zinc on rice crop under Nagaland soil condition.

## MATERIALS AND METHODS

### *Experimental site*

The field experiment entitled "comparative evaluation of zinc application methods on the growth, yield and grain enrichment of rice under hill condition of Nagaland" was conducted at the experimental farm of Department of Agronomy, School of Agricultural Sciences, Medziphema, Nagaland University, Campus: Medziphema, Nagaland, during the *kharif* season of 2023 and 2024. The experimental site is located at about 310 m above mean sea level and falls under a sub-humid tropical climate. The region receives most of its

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**Citation:** Kehokhunu, Gohain T, Sakhong R. 2026. Comparative evaluation of zinc application methods on the growth, yield and grain enrichment of rice under hill condition of Nagaland. *Res. Jr. Agril. Sci*. 17(4): 505-509.

rainfall during the monsoon season from May to October. The initial soil of the experimental field was acidic, with pH of 4.56, electrical conductivity 0.10 dS $m^{-1}$, organic carbon 0.50%, available nitrogen 351.45 kg $ha^{-1}$, available phosphorus 24.45 kg $ha^{-1}$, available potassium 345.82 kg $ha^{-1}$, and available zinc 0.80 mg $kg^{-1}$. The experiment was done in random block design with ten treatments and three replications. The plot size was 4 m × 3 m. Rice was at a spacing of 20 cm × 10 cm using a seed rate of 70 kg $ha^{-1}$. The recommended dose of fertilizer was 60:30:30 kg $N:P_2O_5:K_2O$ $ha^{-1}$. Nitrogen was applied in two equal splits, while the full dose of phosphorus and potassium was applied as basal. $ZnSO_4 \cdot 7H_2O$ (Zinc sulphate heptahydrate), was used as the zinc source as basal soil application, seed priming solution and. Observation was expressed on a per square meter basis ($m^{-2}$). Tiller number was counted on per plant basis and recorded from the five tagged plants The crop growth rate was calculated by taking the dry weight of the tagged plants observed for the time periods of 45 to 60 DAS. Grain and straw yield were recorded from each plot and converted to kg $ha^{-1}$.Harvest index was calculated by dividing the grain yield of the crop by its biological yield multiplied by 100. Wet digestion of plant sample was done with Di-acid mixture (nitric acid and perchloric acid in the ratio of 9:4) Johnson and Ulrich [15]. DTPA extract was done with the help of atomic absorption spectrophotometer (AAS) [16]. The data were statistically analyzed using analysis of variance for randomized block design. Treatment means were compared using critical difference at 5% level of significance.

## RESULTS AND DISCUSSION

*Growth attributes*

Under mean pooled average result, plant population at 90 DAS, $T_5$ i.e., RDF + SP with $ZnSO_4$ @ 2% solution + Foliar application of $ZnSO_4$ @ 0.5%at MT stage and PI stage, (134.53 $m^{-2}$) gave maximum plant population, followed by $T_6$ (RDF + SP with $ZnSO_4$ @ 2% solution +Foliar application of $ZnSO_4$ @ 0.5% at MT stage + PI stage + GF stage) and $T_4$ (RDF + SP with $ZnSO_4$ @ 2% solution + Foliar application of $ZnSO_4$ @ 0.5% at MT stage + PI stage + GF stage). $T_1$ (control) gave the least plant population of 109.63$m^{-2}$. Primed seeds significantly improved germination and plant stand. However, the maintenance and further development depend on the continuous availability of nutrients throughout the crop growth stage. Hence, in terms of plant population at 60 and 90 DAS, it was observed highest with $T_5$ (RDF + seed priming with $ZnSO_4$ @ 2% solution + foliar application of $ZnSO_4$ @ 0.5% at maximum tillering and panicle initiation stages). This may be due to the continuous supply of zinc through foliar application, which in turn may have maintained plant population. An improved number of plants through $ZnSO_4$ foliar spray was reported by Ehsanullah *et al*. [17].

Table 1 Effect of zinc application on the growth attributes of rice

| Treatments | Plant population $m^{-2}$ | | | CGR 45-60 DAS | | |
|---|---|---|---|---|---|---|
| | 2023 | 2024 | Pooled | 2023 | 2024 | Pooled |
| $T_1$: Control | 107.33 | 111.93 | 109.63 | 4.25 | 4.43 | 4.43 |
| $T_2$: RDF | 122.80 | 122.27 | 122.53 | 4.70 | 5.02 | 5.02 |
| $T_3$: RDF + SP @ 2% solution | 128.53 | 130.33 | 129.43 | 8.17 | 8.18 | 8.18 |
| $T_4$: $T_3$ +FA @ 0.5% at MT stage | 131.67 | 132.22 | 131.94 | 9.60 | 9.43 | 9.43 |
| $T_5$: $T_4$ + FA @ 0.5% at PI stage | 133.40 | 135.67 | 134.53 | 10.34 | 10.47 | 10.47 |
| $T_6$: $T_5$ + FA @ 0.5% at GF stage | 131.29 | 133.78 | 132.53 | 10.74 | 10.53 | 10.53 |
| $T_7$: SA @ 15 kg $ha^{-1}$ | 125.44 | 124.11 | 124.78 | 10.56 | 10.74 | 10.74 |
| $T_8$: $T_7$ + FA @ 0.5% at MT stage | 126.44 | 125.80 | 126.12 | 12.25 | 11.65 | 11.65 |
| $T_9$: $T_8$ + FA @ 0.5% at PI stage | 128.00 | 129.22 | 128.61 | 13.68 | 13.27 | 13.27 |
| $T_{10}$: $T_9$ + FA @ 0.5% at GF stage | 121.37 | 127.13 | 124.25 | 12.94 | 12.43 | 12.43 |
| SEm± | 6.27 | 5.57 | 4.19 | 0.84 | 0.58 | 0.58 |
| CD (P=0.05) | NS | NS | 12.03 | 2.50 | 1.67 | 1.67 |

Variations on crop growth rate at 45-60 DAS was significantly influenced by various treatment methods over control in 2023 and 2024 and in pooled data, with the highest CGR) value recorded in $T_9$: RDF + SA of $ZnSO_4$ @ 15 kg $ha^{-1}$ + Foliar application of $ZnSO_4$ @ 0.5% at maximum tillering (MT) + Panicle Initiation (PI) stage. Foliar application of zinc, particularly at maximum tillering and panicle initiation stages, may have improved crop growth by supplying zinc during periods of high physiological need overcoming limitations of zinc availability thereby, ensuring quick nutrient absorption, photosynthate translocation and efficient nutrient utilization by the crop (19-20). This contributed to an improvement in plant growth and dry matter accumulation [18-19]. Paramanik *et al*. [20] also reported significantly higher dry matter accumulation and CGR, with combined basal and foliar Zn application. The higher crop growth rate may be attributed to improved dry matter accumulation and photosynthetic efficiency due to adequate zinc nutrition.

*Yield*

Higher grain yield observed in $T_5$: RDF (Recommended dose of fertilizer) + Seed priming with $ZnSO_4$ @ 2% solution + Foliar application @ 0.5% $ZnSO_4$ at Maximum tillering stage + panicle initiation stage may be due to early vigour of seeds enhanced plant stand. Similarly, Zulfiqar *et al.* [21] reported higher yield as a result of enhanced germination, improved tillering due to adequate Zn availability during germination under primed seed. Which was also in line with the findings of Rehman *et al*. [6] and Reis *et al*. [22]. The maximum rice straw yield (3711.67 kg $ha^{-1}$, 3738.61 kg $ha^{-1}$ and 3725.14 kg $ha^{-1}$) recorded under $T_9$: RDF + SA of $ZnSO_4$ @ 15 kg $ha^{-1}$ + Foliar application of $ZnSO_4$ @ 0.5% at maximum tillering stage + panicle initiation stage in both the cropping season and pooled analysis, respectively, may be attributed to the adequate supply of zinc and nutrients in the rhizosphere [23] along with foliar application at maximum tillering stage and panicle stage, which is similar to the findings of Khatun *et al*. [24] and Praharaj *et* *al*. [25]. The enhancement in vegetative growth and dry matter accumulation in stem and leaves may also be attributed to higher CGR and photosynthetic efficiency, which is also in conformity with the finding of Bharti *et al*. [26]. Although vegetative growth and straw yield were not higher in $T_5$: RDF (Recommended dose of fertilizer) + Seed priming with $ZnSO_4$ @ 2% solution+ Foliar application (FA) @ 0.5% $ZnSO_4$ at Maximum tillering (MT) Stage + Panicle Initiation (PI) Stage, the improved reproductive performance and efficient translocation of assimilates towards grain development in $T_5$ resulted in higher grain yield and superior harvest index as reported by Naik and Das [27] and Arif *et al*. [28]. However, in contrast to its higher straw yield in $T_9$, harvest index saw a reduction with soil application along with foliar application, this may be attributed to the enhanced growth and straw yield. Harvest index is positively correlated with grain yield but negatively correlated with vegetative growth [29]. Higher harvest index depends on the number of productive tillers per square metre and the number of filled grains per panicle under temperate conditions. Sürek and Beşer [30], conversely, these grain attributing yield parameters were observed lower in Treatment 9, despite higher vegetative growth, as a result of which harvest index was minimum in $T_9$. Similar finding was again reported by Jasmin and Rajendran [31].

Table 2 Effect of zinc application on the yield of rice

| Treatments | Grain yield (kg ha$^{-1}$) | | | Straw yield (kg ha$^{-1}$) | | | Harvest index (%) | | |
|---|---|---|---|---|---|---|---|---|---|
| | 2023 | 2024 | Pooled | 2023 | 2024 | Pooled | 2023 | 2024 | Pooled |
| $T_1$: Control | 1023.28 | 1055.49 | 1039.38 | 2306.83 | 2291.39 | 2299.11 | 30.77 | 31.57 | 31.17 |
| $T_2$: RDF | 1209.67 | 1246.68 | 1228.17 | 2585.28 | 2594.17 | 2589.72 | 32.13 | 31.90 | 32.02 |
| $T_3$: RDF + SP @ 2% solution | 1296.06 | 1314.56 | 1305.31 | 2709.72 | 2776.83 | 2743.28 | 32.32 | 32.14 | 32.23 |
| $T_4$: $T_3$ +FA @ 0.5% at MT stage | 1515.89 | 1534.91 | 1525.40 | 2880.83 | 2878.61 | 2879.72 | 34.82 | 34.86 | 34.84 |
| $T_5$: $T_4$ + FA @ 0.5% at PI stage | 1716.00 | 1790.22 | 1753.11 | 3084.72 | 3125.28 | 3105.00 | 35.86 | 36.42 | 36.14 |
| $T_6$: $T_5$ + FA @ 0.5% at GF stage | 1671.11 | 1748.61 | 1709.86 | 3078.61 | 3117.28 | 3097.94 | 35.64 | 35.94 | 35.79 |
| $T_7$: SA @ 15 kg ha$^{-1}$ | 1345.82 | 1397.43 | 1371.63 | 2946.83 | 3031.39 | 2989.11 | 31.36 | 31.55 | 31.45 |
| $T_8$: $T_7$ + FA @ 0.5% at MT stage | 1413.33 | 1466.61 | 1439.97 | 3411.33 | 3495.28 | 3453.31 | 29.41 | 29.54 | 29.47 |
| $T_9$: $T_8$ + FA @ 0.5% at PI stage | 1465.33 | 1521.67 | 1493.50 | 3711.67 | 3738.61 | 3725.14 | 28.32 | 28.88 | 28.60 |
| $T_{10}$: $T_9$ + FA @ 0.5% at GF stage | 1427.50 | 1485.67 | 1456.58 | 3518.00 | 3537.50 | 3527.75 | 28.95 | 29.92 | 29.43 |
| SEm± | 63.62 | 34.70 | 36.24 | 195.17 | 73.32 | 104.24 | 1.41 | 0.88 | 0.83 |
| CD (P=0.05) | 189.04 | 103.11 | 103.93 | 579.87 | 217.86 | 298.99 | 4.19 | 2.63 | 2.39 |

*Zinc concentration in grain*

Result showed that $T_{10}$ (RDF + SA of $ZnSO_4$ @ 15 kg ha$^{-1}$ + Foliar application of $ZnSO_4$ @ 0.5% at Maximum tillering (MT) stage + Panicle Initiation (PI) stage + GF stage) prevailed over other treatment methods. Among different Zn treatments applications, $T_{10}$: Recommended dose of fertilizer **(RDF)** + soil application of $ZnSO_4$ @ 15 kg ha$^{-1}$ + foliar application of 0.5% $ZnSO_4$ at maximum tillering and panicle initiation stages + grain filling stage gave maximum nutrient Zn content in grain and straw of rice in 2023, 2024 and pool result. Zn in grain, registered an increase of 73.57% over control, %. under pooled basis.

Table 3 Effect of zinc application on zinc content of rice

| Treatments | Zinc (mg kg $^{-1}$) | | |
|---|---|---|---|
| | 2023 | 2024 | Pooled |
| $T_1$: Control | 25.00 | 25.70 | 25.35 |
| $T_2$: Recommended dose of fertilizer (RDF) | 26.00 | 26.86 | 26.43 |
| $T_3$: RDF + SP@2% solution | 28.67 | 29.18 | 28.92 |
| $T_4$: $T_3$ + F. A @ 0.5% at M.T stage | 31.00 | 33.71 | 32.36 |
| $T_5$: $T_4$ + F. A @ 0.5% at P. I stage | 32.33 | 34.22 | 33.28 |
| $T_6$: $T_5$ + F. A @ 0.5% at G.F stage | 35.00 | 35.75 | 35.37 |
| $T_7$: B.A @ 15 kg ha$^{-1}$ | 29.33 | 31.18 | 30.26 |
| $T_8$: $T_7$ + F. A @ 0.5% at M.T stage | 33.00 | 35.33 | 34.17 |
| $T_9$: $T_8$ + F. A @ 0.5% at P. I stage | 40.71 | 42.91 | 41.81 |
| $T_{10}$: $T_9$ + F. A @ 0.5% at G.F stage | 43.66 | 44.33 | 44.00 |
| SEm± | 1.73 | 2.31 | 1.44 |
| CD (P=0.05) | 5.13 | 6.88 | 4.14 |

Improvement under $T_{10}$: RDF + SA of $ZnSO_4$ @ 15 kg ha$^{-1}$ + Foliar application of $ZnSO_4$ @ 0.5% at MT stage + PI stage + GF stage, may be due to the synergistic effect of nutrients with zinc which enhanced absorption of several minerals in plants [32]. Furthermore, the continuous Zn availability and balanced nutrients around the seeds in soil rhizosphere [33] along with foliar application especially at the grain filling stage enriched grain zinc concentration. Foliar Zn application at maximum tillering stage primarily enhances vegetative growth during the plant's most active vegetative growth phases, whereas application at panicle initiation is more effective for Zn and nutrients enrichment due to enhanced nutrient remobilization and partitioning towards developing grains Tuiwong *et al*. [34]. The present findings are in agreement with Saleem *et al*. [18], who reported that basal soil Zn application provides a steady supply throughout the growth period whereas the additional foliar spray acts as a supplementary approach to provide additional Zn during critical growth phase. Hence, rescheduling Zn application from early to late growth stage significantly enhances Zn sequestration in grain. This is in conformity with the findings of Saha *et al*. [35], Phattarakul *et al*. [36] and Yogi *et al*. [37] who also similarly opined that foliar application at flowering stage or at key reproductive stage as the best strategy to biofortify rice, which ultimately resulted in higher grain zinc content.

## CONCLUSION

The study showed that zinc biofortification practices significantly influenced growth, grain yield and grain zinc content. Among the treatments, RDF + seed priming with 2% $ZnSO_4$ + foliar application of 0.5% $ZnSO_4$ at maximum tillering and panicle initiation stages was the most effective treatment for improving grain yield for zinc biofortification, recommended dose of fertilizer (RDF) + soil application of $ZnSO_4$ at 15 kg $ha^{-1}$ + foliar application of 0.5% $ZnSO_4$ at maximum tillering, panicle initiation, and grain-filling stages was most effective, recording the highest grain zinc content of 44.00 mg $kg^{-1}$. Therefore, for farmers prioritizing grain yield and seed priming with 2% $ZnSO_4$ followed by foliar zinc spray at maximum tillering and panicle initiation stages may be recommended. For targeting maximum grain zinc enrichment, soil application of $ZnSO_4$ combined with foliar sprays up to grain filling may be more suitable under Nagaland condition.

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