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Effect of Foliar Applied Zinc Chelate (Zn-HEDP) on Growth and Productivity of Paddy Crop in the Western Gangetic Region of Uttar Pradesh

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***Abstract*:** Zinc deficiency is a critical yield-limiting factor in rice cultivation across the Western Gangetic Plains of India. A field experiment was conducted during the kharif seasons of 2023 and 2024 at Saharanpur, Uttar Pradesh, to evaluate the effect of foliar-applied zinc chelate (Zn-HEDP) on growth, yield attributes and productivity of transplanted paddy. Nine treatments comprising chelated and inorganic zinc sources applied with and without farmyard manure (FYM) were tested in a randomized block design with three replications. Yield and yield attributes were recorded season-wise and analyzed separately. Application of Zn-HEDP, particularly in combination with FYM, significantly enhanced tillering, panicle length, grain filling, test weight and grain yield compared to the farmer's practice. Yield improvements were more pronounced during the second season, indicating cumulative physiological benefits. The study highlights Zn-HEDP as an effective zinc source for improving rice productivity and grain zinc enrichment in zinc-deficient alluvial soils of the Western Gangetic region.

Keywords: Zn-HEDP, rice productivity, foliar zinc, yield attributes, biofortification

INTRODUCTION

Rice (*Oryza sativa* L.) is the staple food crop of India, sustaining more than half of the population and occupying a pivotal role in national food security. In the Indo-Gangetic Plains, intensive rice cultivation under high fertilizer use and limited micronutrient replenishment has accelerated zinc deficiency, leading to yield stagnation and poor grain nutritional quality (Cakmak, 2009; Alloway, 2008). Zinc plays a multifunctional role in rice physiology, influencing tiller emergence, chlorophyll synthesis, pollen viability, grain filling and stress tolerance (Marschner, 1995; Cakmak, 2000). In zinc-deficient soils, rice exhibits reduced tillering, smaller panicles and poor grain development, ultimately lowering productivity. Although soil application of zinc sulphate is commonly recommended, its efficiency is often constrained by soil fixation and uneven availability (Shivay *et al.*, 2016). Foliar application of chelated zinc offers a rapid and efficient alternative, directly supplying zinc during critical growth stages. Zinc chelated with hydroxyethylidenediphosphonic acid (Zn-HEDP) has gained attention due to its high stability, enhanced solubility and superior plant availability (Sekhon, 2003; Singh *et al.*, 2020). However, limited field-based evidence is available on its season-wise impact on rice productivity under Western Gangetic conditions. Therefore, the present study

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was undertaken to evaluate the effect of foliar-applied Zn-HEDP on yield attributes and productivity of transplanted rice during two consecutive cropping seasons.

2. MATERIALS AND METHODS

2.1. Experimental site

The experiment was conducted during 2023 and 2024 at farmers' fields in Rampur Maniharan, Saharanpur district, Uttar Pradesh. The district lies between 77°15′ and 76°00′ east longitude and 27°10′ and 29°34′ north latitude, at an altitude of approximately 275.05 m above mean sea level. The region is agriculturally important and lies below the foothills of the Himalayas.

2.2. Climate and weather conditions

The climate of the study area is **semi-arid subtropical**, characterized by hot summers and cold winters. Summer temperatures may rise to 45-48°C, whereas winter temperatures may fall below 5°C. Most rainfall is received through the southwest monsoon.

Table 1: Meteorological data during the Paddy growing period

Month	*Mintemp. (°C)*	*Max temp. (°C)*	*Avg temp. (°C)*	*Min RH (%)*	*Max RH (%)*	*Avg RH (%)*	*Rainfall (mm)*
Season I (2023)							
Jun-23	22.3	40.0	31.2	63.0	100.0	81.5	303.0
Jul-23	23.2	37.5	30.4	75.0	100.0	87.5	1065.0
Aug-23	26.5	35.0	30.8	72.0	100.0	86.0	249.5
Sep-23	25.0	35.5	30.3	71.0	100.0	85.5	142.5
Oct-23	19.0	32.5	25.8	55.0	92.0	73.5	37.0
Season II (2024)							
Jun-24	28.0	45.5	36.8	79.0	100.0	89.5	36.8
Jul-24	25.0	37.5	31.3	78.0	100.0	89.0	31.3
Aug-24	27.0	36.0	31.5	82.0	100.0	91.0	31.5
Sep-24	23.0	37.0	30.0	79.0	100.0	89.5	30.0
Oct-24	20.0	35.6	27.8	74.0	98.0	86.0	27.8

2.3. Soil characteristics

The soil was sandy loam in texture. Pre-sowing soil analysis indicated medium organic carbon and medium available nitrogen, phosphorus, and potassium status, with near-neutral to slightly alkaline soil reaction and non-saline conditions.

Table 2: Initial physico-chemical properties of experimental soil

Property	*2023*	*2024*
Fine sand (%)	54.8%	55.1%
Silt (%)	20.9%	21.1%
Clay (%)	20.8%	21.0%
Texture	Sandy loam	Sandy loam
Organic carbon (%)	0.59	0.61
Available N (kg/ha)	296	298
Available P (kg/ha)	24	26
Available K (kg/ha)	278	282

2.4. Treatments and experimental design

The experiment was laid out in Randomized Block Design (RBD) with 9 treatments and 3 replications.

Table 3: Treatment details

Treatment	*Combination*
T1	Zn-HEDP 17% @ 400 gm/acre
T2	Zn-HEDP 17% @ 400 gm/acre + FYM @ 2 t/acre
T3	Zn-EDTA 12% @ 150 gm/acre
T4	Zn-EDTA 12% @ 150 gm/acre + FYM@ 2 t/acre
T5	ZnSO4 heptahydrate 21% @ 10 kg/acre
T6	ZnSO4 heptahydrate 21% @ 10 kg/acre + FYM@ 2 t/acre
T7	ZnSO4 monohydrate 33% @ 5 kg/acre
T8	ZnSO4 monohydrate 33% @ 5 kg/acre + FYM@ 2 t/acre
T9	Untreated/farmer practice (RDF)

3. RESULTS AND DISCUSSION

3.1. Growth Parameters Of Rice

The data associated with growth parameters of rice under different treatments is depicted in table 4.

(i) Effect on Tillering: The number of tillers is a primary determinant of yield in rice as it directly influences panicle density per unit area. The data on productive and total tillers recorded during both seasons clearly showed a significant response to zinc fertilization.

Kharif 2023

During 2023, the farmer's practice (T9) recorded the lowest number of productive tillers (12.80 hill-^{1}) and total tillers (14.02 hill-^{1}). All zinc-treated plots produced significantly higher tiller counts. The highest number of productive tillers (16.30 hill-^{1}) and total tillers (18.40 hill-^{1}) was recorded under T2 (Zn-HEDP 17% @ 400 g acre-^{1} + FYM @ 2 t acre-^{1}). This treatment was statistically superior to all other treatments. Among the remaining zinc treatments, T6 (ZnSO- heptahydrate + FYM) and T8 (ZnSO- heptahydrate + FYM) recorded 15.40 and 14.67 productive tillers hill-^{1}, respectively, forming the next best group. Zinc applied alone (T1, T3, T5 and T7) recorded intermediate values ranging from 13.90 to 14.20 productive tillers hill-^{1}, y*et al*l were significantly superior to the control.

Kharif 2024

A similar but slightly enhanced trend was observed during 2024. T9 again recorded the minimum productive tillers (12.50 hill-^{1}). T2 produced the maximum tillers (15.80 productive tillers and 17.90 total tillers hill-^{1}), confirming season-to-season consistency. The overall increase during 2024 indicates a cumulative physiological response to Zn-HEDP, particularly when combined with FYM. Zinc enhances auxin synthesis and meristematic activity, resulting in increased tiller initiation and survival.

(ii) Effect on Panicle Length: Panicle length represents sink size and potential grain number.

Kharif 2023

Panicle length at harvest ranged from 23.20 cm in T9 to 24.40 cm in T2. Treatments T1 (24.30 cm) andT2 (24.40 cm) were significantly superior to RDF, while all other treatments remained statistically at par with the control.

Kharif 2024

In 2024, panicle length increased slightly across treatments. T2 again recorded the maximum (24.20 cm), followed closely by T1 (24.0 cm), T4 (23.90 cm) and T8 (23.90 cm). Enhanced panicle elongation under Zn-HEDP reflects improved nutrient translocation and spikelet differentiation during reproductive stages.

(iii) Effect on Grain Filling and Test Weight

Filled Grains per Panicle

In 2023, T9 recorded the lowest filled grains (160.80 panicle-^{1}). T2 recorded the highest value (170.50 panicle-^{1}), which was significantly superior to all treatments. All Zinc applied treatments were also superior to RDF, whereas zinc-alone treatments showed moderate improvements. This trend continued in 2024, where T2 consistently maintained the highest grain filling, indicative of improved pollen viability and carbohydrate translocation under zinc sufficiency.

Test Weight (1000-grain weight)

Test weight showed a strong response to zinc management. All zinc-treated plots were significantly superior to RDF in both years. Higher test weight under Zn-HEDP indicates better grain density and starch accumulation. In 2023, T9 recorded the lowest 1000 grain weight (20.30 gm) while T2 recorded the highest value (22.40 gm) which was significantly superior

Table 4: Effect of Different Zinc treatments on different growth parameters of Paddy crop

Treatment No.	*Treatment Details*	*Total No. of Tillers*		*No. of productive Tillers*		*Panicle length (cm)*		*Number of filled grain/ Panicle*		*Test weight (gm) (1000 grains)*	
		2023	*2024*	*2023*	*2024*	*2023*	*2024*	*2023*	*2024*	*2023*	*2024*
T1	Zn-HEDP 17%	15.3	15.9	14.20	13.80	24.3	24.0	164.3	167.2	21.80	22.7
T2	Zn-HEDP 17% +FYM	18.4	17.9	16.30	15.80	24.4	24.2	170.5	173.8	22.40	23.2
T3	Zn-EDTA 12%	15.3	15.8	13.90	13.71	23.6	23.4	163.6	165.3	21.30	22.1
T4	Zn-EDTA 12% + FYM	16.2	16.9	14.60	14.30	24.0	23.9	165.8	166.5	21.30	22.5
T5	$ZnSO_4$ heptahydrate 21%	15.5	16.3	14.10	13.50	23.3	23.1	165.0	166.7	21.10	22.1
T6	$ZnSO_4$ heptahydrate 21% + FYM	15.4	15.6	15.40	13.70	23.9	23.7	166.3	167.2	21.70	22.5
T7	$ZnSO_4$ monohydrate 33%	15.3	16.1	13.90	13.90	23.7	23.2	164.3	166.0	21.10	22.5
T8	$ZnSO_4$ monohydrate 33% + FYM	15.4	15.7	14.67	14.30	24.1	23.9	166.2	167.9	22.10	22.3
T9	Untreated/farmer practice (RDF)	14.2	13.8	12.80	12.50	23.2	22.9	160.8	164.4	20.30	21.1
	CD 5%	0.91	1.13	0.87	0.91	0.97	0.89	3.34	3.89	0.38	0.45
	SE	0.38	0.51	0.41	0.43	0.42	0.39	1.45	1.87	0.19	0.23

Table 5: Effect of Different Zinc treatments on Grain and Straw Yieldof Paddy crop

Treatment No.	*Treatment Details*	*Grain yield (kg/ha)*		*straw yield (kg/ha)*	
		2023	*2024*	*2023*	*2024*
T1	Zn-HEDP 17%	6699.60	6796.24	10567.30	10409.30
T2	Zn-HEDP 17% + FYM	6848.95	6980.30	10654.30	10726.15
T3	Zn-EDTA 12%	6600.70	6620.45	10065.70	10037.27
T4	Zn-EDTA 12% + FYM	6612.30	6719.95	10551.20	10423.23
T5	ZnSO4 heptahydrate 21%	6616.20	6749.85	10414.30	10366.24
T6	ZnSO4 heptahydrate 21% + FYM	6640.40	6764.05	10741.40	10613.29
T7	ZnSO4 monohydrate 33%	6604.25	6710.21	10406.90	10250.79
T8	ZnSO4 monohydrate 33% + FYM	6670.15	6793.80	10588.20	10460.09
T9	Untreated/farmer practice (RDF)	6420.15	6543.80	9967.90	9744.79
	CD 5%	161.42	140.56	339.58	389.78
	SE	78.56	68.96	174.68	191.78

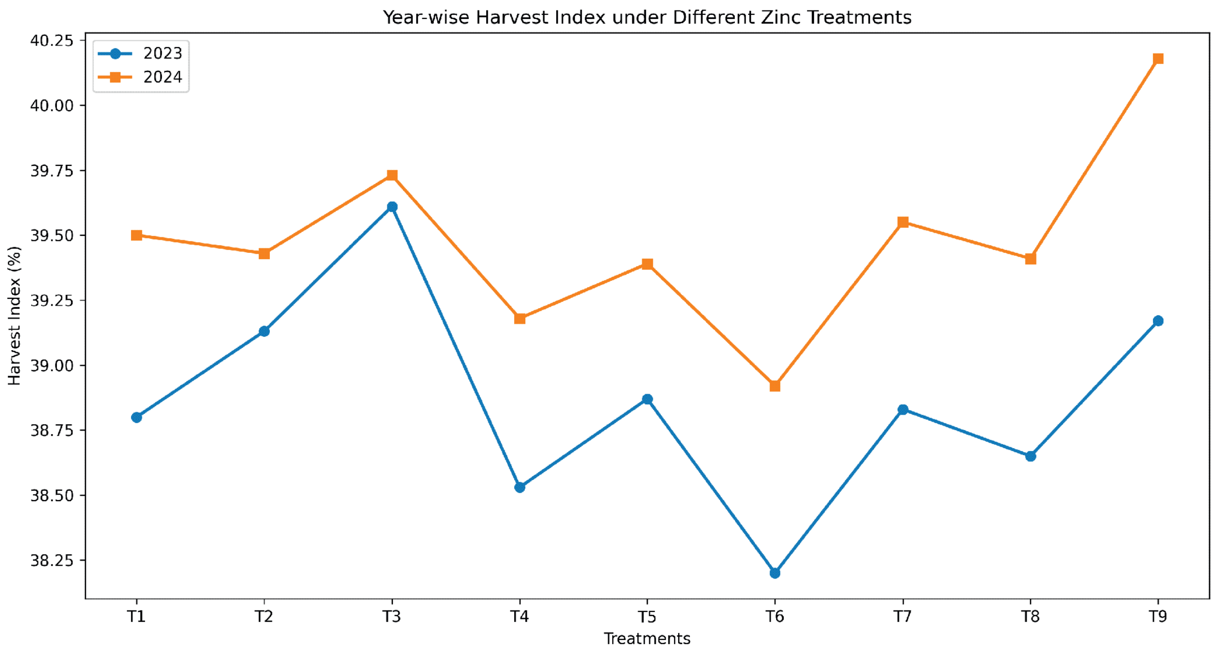

Figure 1: Harvest index of paddy under different Zinc treatments in the year 2023 and 2024.

to most of thetreatments. All Zinc applied treatments were also superior to RDF, whereas zinc-alone treatments showed moderate improvements. This trend continued in 2024, where T2 consistently maintained the highest grain filling, indicative of improved pollen viability and carbohydrate translocation under zinc sufficiency.

3.2. Effect on Grain and Straw Yield

(i) Yield parameters of rice

The data related to the yield parameters of rice are given in table no. Table 5

Grain Yield

Kharif 2023: Grain yield ranged from 6420.15 kg ha-1 in T9 to 6848.95 kg ha-1 in T2. T2 was significantly superior to all other form of Zinc treatments. Zinc-alone treatments recorded intermediate yields:

Kharif 2024: Yield increased slightly across all treatments in 2024: The persistent superiority of T2 confirms the stability and reliability of Zn-HEDP + FYM.

(ii) Straw Yield

Straw yield followed grain yield closely. T2 and T6 recorded the maximum straw yield (≈

10.7 t ha-¹) in 2023 and 2024 which was closely followed by T8while T9 recorded the lowest in both seasons. Enhanced biomass accumulation reflects improved photosynthesis and nutrient uptake. Several studies have shown that the combined use of FYM and mineral fertilizers enhances nutrient use efficiency, crop yields, and soil organic carbon compared with mineral fertilizers alone in rice–based systems (Ladha *et al*., 2003; Mandal *et al*., 2007; Gill *et al*., 2008). Organic matter can complex Zn and prevent its immediate fixation, while mineralization processes gradually release Zn into soil solution, contributing to a more sustained supply (Katyal & Sharma, 1991; Alloway, 2008). Similar observations were also reported by Shukla and Tiwari (2016) that the application of Zinc fertilizers resulted into a 9 to 12% increase in rice yield.

(ii) Harvest Index

The harvest index of paddy was marginally influenced by different zinc treatments during both years of experimentation. In 2023, harvest index values ranged from 38.20 to 39.61%, whereas in 2024 the values varied between 38.92 and 40.18%. Among the treatments, T3 (Zn-EDTA 12%) recorded comparatively higher harvest index values during both years, while T6 (ZnSO- heptahydrate 21% + FYM) exhibited relatively lower values. The untreated control (T9) showed the highest harvest index during 2024. Overall, only slight variations in harvest index were observed among treatments, indicating that zinc fertilization enhanced both grain and straw yield proportionally. The relatively stable harvest index across treatments suggests balanced partitioning of assimilates between economic and vegetative biomass under zinc nutrition.

CONCLUSION

The present investigation clearly demonstrates that foliar application of Zn-HEDP significantly enhances growth, yield attributes and productivity of paddy under zinc-deficient alluvial soils of the Western Gangetic Plains. The integrated use of Zn-HEDP with FYM produced the highest yields. Season-wise improvements were more pronounced during the second year, highlighting cumulative benefits. (Zn-HEDP 17% @ 400 g acre-¹ + FYM @ 2 t acre-¹) may therefore be recommended as an efficient zinc management strategy for sustainable rice production in the region.

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