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Effect of foliar applied zinc chelate (Zn HEDP) on soil properties in Western Gangetic Region of Uttar Pradesh

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Abstract
Zinc deficiency is emerging as a major constraint to soil fertility and crop productivity in intensively cultivated rice ecosystems of the Indo-Gangetic Plains. A field experiment was conducted during the kharif seasons of 2023 and 2024 at Saharanpur, Uttar Pradesh, to study the effect of foliar-applied zinc chelate (Zn-HEDP) on post-harvest soil properties under transplanted paddy. Nine treatments comprising chelated and inorganic zinc sources with and without farmyard manure (FYM) were evaluated in a randomized block design with three replications. Soil samples collected after harvest each season were analyzed separately for available nitrogen, phosphorus and potassium, organic carbon, pH and electrical conductivity. Results revealed that foliar application of Zn-HEDP, particularly in combination with FYM, significantly improved available phosphorus and marginally enhanced nitrogen and potassium status without adversely affecting soil pH, EC, bulk density or $CaCO_3$ content. Improvements were more pronounced during the second season, indicating residual and cumulative benefits. The study demonstrates that Zn-HEDP is an efficient and soil-safe micronutrient source for sustaining soil fertility in zinc-deficient alluvial soils of the Western Gangetic region.

Keywords: Zinc chelate, Zn-HEDP, soil fertility, available nutrients, rice soil, Western Gangetic Plains

Introduction
Zinc (Zn) is an essential micronutrient involved in several physiological and biochemical processes in plants, including enzyme activation, protein synthesis, auxin metabolism and membrane stability (Marschner, 1995; Alloway, 2008) [1, 7]. In addition to its direct role in crop nutrition, zinc contributes indirectly to soil health by influencing microbial activity, nutrient cycling and rhizosphere dynamics (Rengel, 2003).
In India, nearly half of the cultivated soils are deficient in plant-available zinc, particularly in intensively cultivated rice–wheat systems of the Indo-Gangetic Plains (Cakmak, 2009) [4]. Under such conditions, conventional soil application of zinc sulphate often suffers from fixation, leaching or precipitation losses, especially in neutral to alkaline alluvial soils (Shivay *et al*., 2016) [12].
Foliar application of zinc chelates has emerged as an effective alternative, ensuring rapid nutrient uptake and improved utilization efficiency. Among chelated forms, zinc chelated with hydroxyethylidene diphosphonic acid (Zn-HEDP) has received attention due to its high stability, solubility and low fixation tendency (Sekhon, 2003; Singh *et al*., 2020) [11, 13]. However, limited information is available on the season-wise impact of foliar Zn-HEDP on post-harvest soil properties, particularly under the rice ecosystem of Western Uttar Pradesh.
Therefore, the present investigation was undertaken to evaluate the influence of foliar-applied Zn-HEDP on soil fertility parameters following rice cultivation during two consecutive seasons.

Materials and Methods
The experiment was conducted during the kharif seasons of 2023 and 2024 at Rampur Maniharan, Saharanpur district of Uttar Pradesh, situated in the Western Gangetic Plains. The soil of the experimental site was sandy loam in texture, neutral to slightly alkaline in reaction and deficient in available zinc. Nine treatments comprising Zn-HEDP, Zn-EDTA and zinc sulphate (heptahydrate and monohydrate) applied with and without FYM, along with a farmer's practice (RDF), were evaluated in a Randomized Block Design with three replications. After harvest of rice in each season, soil samples were collected from 0–15 cm depth and analyzed for available nitrogen, phosphorus and potassium, organic carbon, soil pH and electrical conductivity using standard analytical procedures.

Initial Soil Properties

S. No.	Soil properties	2023	2024
1	Available Nitrogen (kg/ha)	296	298
2	Available Phosphorus (kg/ha)	24	26
3	Available Potash (kg/ha)	278	282
4	Organic carbon (%)	0.59	0.61
5	pH	7.2	7.1
6	Electric conductivity (dS/m)	0.29	0.28

Results and Discussion

Effect on Soil Properties after Harvest during Kharif 2023 [9]

The data on post-harvest soil fertility status during the 2023 [9] season are presented in Table 1 and Table 2.

Available Nitrogen

Available nitrogen content varied from 297.13 kg ha⁻¹ under the RDF control to 301.65 kg ha⁻¹ under Zn-EDTA 12% + FYM. Although differences were relatively small, treatments receiving FYM in combination with zinc recorded numerically higher available nitrogen. This improvement may be attributed to enhanced mineralization and reduced nitrogen losses due to improved soil biological activity. However, most zinc treatments remained statistically at par with RDF, indicating that zinc fertilization primarily influenced crop uptake rather than residual nitrogen accumulation.

Available Phosphorus

Marked differences were recorded with respect to soil available phosphorus. Zn-HEDP + FYM recorded the highest phosphorus availability (32.76 kg ha⁻¹), followed by Zn-HEDP alone (30.65 kg ha⁻¹), both of which were significantly superior to all other treatments. The improvement in phosphorus availability under Zn-HEDP treatments can be attributed to chelation effects reducing phosphorus fixation and enhanced rhizosphere activity, corroborating the findings of Rengel (2003) and Broadley *et al*. (2012).

Available Potassium

Available potassium showed only marginal variation among treatments, ranging from 282.10 kg ha⁻¹ in RDF to 285.38 kg ha⁻¹ in Zn-EDTA 12% + FYM. The slight increase under FYM-based treatments may be due to improved cation exchange capacity rather than a direct zinc–potassium interaction.

Organic Carbon, EC and pH

Soil organic carbon ranged between 0.59 and 0.64%, with slightly higher values under FYM-integrated treatments. Soil pH (6.8–7.2) and electrical conductivity (0.26–0.31 dS m⁻¹) remained statistically at par across treatments, indicating that Zn-HEDP application did not adversely affect soil chemical properties.

Effect on Soil Properties after Harvest during Kharif 2024

The post-harvest soil fertility status for the 2024 season is presented in Table 1 and Table 2, which shows more pronounced treatment effects compared to 2023 [9].

Available Nitrogen

Available nitrogen ranged from 296.95 kg ha⁻¹ in RDF to 302.56 kg ha⁻¹ under Zn-EDTA 12% + FYM. All the Zinc treatments were at par with each other which indicates that the application of Zinc in any form does alter the nitrozen residues in soil. The improvement observed during the second season indicates cumulative benefits of integrated zinc and organic nutrient management.

Available Phosphorus

Available phosphorus exhibited a strong residual response. Zn-HEDP + FYM recorded the highest value (34.45 kg ha⁻¹), followed by Zn-HEDP alone (31.23 kg ha⁻¹), both significantly superior to RDF (26.25 kg ha⁻¹). The year-to-year increase clearly demonstrates the sustained effectiveness of chelated zinc in improving phosphorus availability.

Available Potassium

Available potassium showed a gradual improvement under FYM-based treatments, with Zn-EDTA 12% + FYM recording the highest level (287.6 kg ha⁻¹). This reflects improved nutrient retention and soil structural stability.

Organic Carbon, pH and EC

Organic carbon increased slightly under Zn with FYM enrichments, indicating cumulative organic matter effects. Soil pH and EC remained stable and unaffected across treatments, confirming the soil-safe nature of Zn-HEDP application even under repeated use.

Meena *et al*. (2018) [8] reported that applying zinc-enriched FYM led to a significant rise in available nitrogen, organic carbon and DTPA-extractable zinc as enrichment levels increased. Nandy *et al*. (2022) demonstrated that integrating organic manure, inorganic fertilizer and foliar zinc spray delivers a powerful boost to soil microbial populations—far surpassing the impact of chemical fertilizer alone. This approach unlocks greater nutrient availability and cultivates optimal conditions for microbial growth. Bahadur *et al*. (2012), Kumari *et al*. (2017) [2, 6] and Kumar *et al*. (2018) reported similar results, reinforcing this perspective.

Table 1: Effect of Different Zinc treatments on soil fertility (NPK content at harvest)

Treatment No.	Treatment Details	Potash in soil after harvesting (kg/ha)		Phosphorus in soil after harvesting (kg/ha)		Available nitrogen in soil after harvesting (kg/ha)	
		2023	2024	2023	2024	2023	2024
T_1	Zn-HEDP 17%	284.10	284.50	30.65	31.23	297.56	298.40
T_2	Zn-HEDP 17% +FYM	284.56	286.50	32.76	34.45	298.56	301.30
T_3	Zn-EDTA 12%	283.10	283.20	24.65	25.23	299.12	299.97
T_4	Zn-EDTA 12% + FYM	285.38	287.60	25.98	25.91	301.65	302.56
T_5	ZnSO4 heptahydrate 21%	283.80	283.40	26.98	26.35	299.90	301.14
T_6	ZnSO4 heptahydrate 21% + FYM	285.21	286.90	27.67	28.13	301.16	302.34
T_7	ZnSO4 monohydrate 33%	283.60	284.10	26.78	26.34	297.16	297.45
T_8	ZnSO4 monohydrate 33% + FYM	284.45	286.60	27.43	28.90	298.20	301.01
T_9	Untreated/farmer practice (RDF)	282.10	282.90	25.98	26.25	297.13	296.95
	CD	2.97	3.56	2.13	3.71	3.53	4.23
	SE	1.23	1.78	1.01	1.96	1.78	1.98

Table 2: Effect of Different Zinc treatments on soil properties: Organic carbon, electrical conductivity, pH

Treatment No.	Treatment Details	Organic carbon in soil (%)		EC in soil (ds/m)		Soil pH after harvest	
		2023	2024	2023	2024	2023	2024
T_1	Zn-HEDP 17%	0.59	0.59	0.26	0.25	6.90	7.20
T_2	Zn-HEDP 17% +FYM	0.63	0.64	0.26	0.25	7.10	7.30
T_3	Zn-EDTA 12%	0.61	0.61	0.28	0.27	7.10	7.30
T_4	Zn-EDTA 12% + FYM	0.64	0.65	0.31	0.3	6.90	7.00
T_5	ZnSO4 heptahydrate 21%	0.60	0.61	0.26	0.27	6.80	6.90
T_6	ZnSO4 heptahydrate 21% + FYM	0.63	0.63	0.28	0.27	7.10	6.80
T_7	ZnSO4 monohydrate 33%	0.60	0.59	0.27	0.28	6.90	7.20
T_8	ZnSO4 monohydrate 33% + FYM	0.62	0.63	0.26	0.26	7.20	7.10
T_9	Untreated/farmer practice (RDF)	0.60	0.61	0.26	0.27	7.10	6.80
	CD	0.03	0.03	0.05	0.05	0.40	0.50
	SE	0.01	0.01	0.02	0.02	0.15	0.23

Conclusion

The study conclusively demonstrates that foliar application of Zn-HEDP, particularly when integrated with FYM, significantly improves post-harvest soil fertility, especially available phosphorus, without adversely affecting soil physico-chemical properties. Residual benefits were more evident during the second season, highlighting its sustainability. Zn-HEDP can therefore be recommended as an efficient and environmentally safe zinc source for maintaining soil fertility in the zinc-deficient rice soils of the Western Gangetic Plains.

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