**Integrated Use of Zinc-Based Fertilizers and Biofertilizer Enhances Soil Fertility in Alkaline Soils of U.P.**

## ABSTRACT

A field experiment was conducted during the 2022 *Kharif* season at the Student Instructional Farm, ANDUAT, Ayodhya, to evaluate the effect of zinc-based fertilizers and biofertilizers on soil fertility. The study consisted of eight treatments, including various combinations of recommended fertilizer dose (RDF), zinc sulphate, zinc oxide, and zinc-mobilizing bacteria (ZMB), laid out in a randomized block design with three replications. The results revealed that the integrated use of RDF with 5.0 kg ha⁻¹ zinc sulphate and ZMB significantly improved soil fertility indices, including pH, organic carbon, and available macro- and micronutrients. The application of RDF (100%) + 5.0 Zn ha-1 (Zinc Sulphate) + Biofertilizer (ZMB) was recorded maximum availability of nutrient in soil (N, P, K) at post-harvest analysis.

**Keywords:** *Zinc sulphate, Zinc mobilizing bacteria, Soil fertility, Biofertilizer*

## INTRODUCTION

Zinc (Zn) plays a crucial role in various physiological and biochemical processes in plants, including enzyme activation, protein synthesis, and membrane integrity. Deficiency of zinc is a major constraint in rice-growing areas, especially in calcareous, alkaline, and submerged soils where zinc becomes unavailable to plants. Studies have reported that nearly 50% of Indian soils are deficient in available zinc, severely limiting crop yields and grain nutritional quality (Cakmak, 2009). Soil fertility is a cornerstone of sustainable agricultural productivity, particularly in regions where edaphic constraints limit crop performance. In the Indo-Gangetic plains of Uttar Pradesh (U.P.), a significant proportion of agricultural land is characterized by alkaline soils, which pose a major challenge to nutrient availability and uptake. Alkaline soils, typically with a pH above 8.0, are known to impede the solubility and mobility of essential micronutrients-most notably zinc (Zn)-thereby affecting plant growth, yield, and nutritional quality. Zinc is a vital micronutrient involved in numerous physiological and biochemical processes in plants, including enzyme activation, protein synthesis, and growth regulation. Its deficiency is widespread in Indian soils, particularly in alkaline and calcareous regions, where zinc becomes immobilized and unavailable to plants. According to recent estimates, over 50% of soils in U.P. are zinc-deficient, leading to suboptimal crop yields and reduced grain quality (Singh *et al.*, 2005). Conventional zinc fertilization, such as the application of zinc sulfate (ZnSO4), has been widely practiced; however, its efficiency is often compromised by rapid fixation in high-pH soils. In this context, chelated forms of zinc, such as, have emerged as more effective alternatives due to their higher solubility and sustained release. Simultaneously, the use of biofertilizers-microbial inoculants that enhance nutrient availability through biological processes-has gained prominence as an eco-friendly and cost-effective strategy. Biofertilizers such as zinc mobilizing bacteria (ZMB) not only improve zinc availability but also contribute to better root development and microbial activity in the rhizosphere, potentially enhancing micronutrient uptake (Yadav *et al.,* 2020). The integrated use of zinc-based fertilizers and biofertilizers offers a promising approach to address the dual challenges of micronutrient deficiency and declining soil health in alkaline soils. While individual effects of zinc fertilizers and biofertilizers have been studied extensively, there is limited research on their synergistic impact under field conditions in the alkaline soils of U.P.

Traditional zinc fertilization methods, such as the application of zinc sulphate or zinc oxide, are often inefficient due to the rapid conversion of zinc into insoluble forms in high pH soils. Moreover, the excessive and unbalanced use of chemical fertilizers adversely affects soil health and sustainability. An eco-friendly alternative is the use of biofertilizers such as zinc mobilizing bacteria (ZMB), which are known to solubilize unavailable zinc and enhance its uptake by plants. These bacteria not only improve zinc availability but also promote plant growth by secreting organic acids, phytohormones, and other growth-promoting substances. The integrated use of chemical zinc sources and ZMB has the potential to improve enhancing soil fertility. However, studies on their combined effect under the specific agro-climatic conditions of eastern Uttar Pradesh, especially in silty loam soils, are limited.

Therefore, the present investigation was undertaken to study the effect of zinc-based fertilizers and zinc mobilizing biofertilizer on soil fertility under silty loam soil conditions.

## MATERIALS AND METHODS

**Study Area:** The field experiment was conducted during the *Kharif*, 2022 at Student Instructional Farm, ANDUAT, Kumarganj, Ayodhya, situated in the alkaline soil region of Uttar Pradesh, India. The experimental site is characterized by a semi-arid climate with average annual rainfall of approximately 700 mm.

**Experimental Design:** The study was laid out in a randomized block design (RBD) with three replications. The treatments consisted of combinations of zinc-based fertilizers and biofertilizers applied to rice. The following treatments were evaluated: Eight treatments were arranged in a Randomized Block Design (RBD) with three replications: T1: RDF (150:60:40 kg N:P:K ha-1), T2: RDF + 2.5 kg Zn ha-1 (Zinc sulphate), T3: RDF + 5.0 kg Zn ha-1 (Zinc sulphate), T4: RDF + 2.5 kg Zn ha-1 (Zinc oxide), T5: RDF + 5.0 kg Zn ha-1 (Zinc oxide), T6: RDF + Biofertilizer (ZMB), T7: RDF + 5.0 kg Zn ha-1 (Zinc sulphate) + Biofertilizer (ZMB), T8: RDF + 2.5 kg Zn ha-1 (Zinc sulphate) + 2.5 kg Zn ha-1 (Zinc oxide) + Biofertilizer (ZMB).

**Soil and Fertilizer Application:** To nourish the rice, a fertilizer dose of 150:60:40 kg NPK ha-1 was applied. Half of the nitrogen dose and the full dose of phosphorus and potassium were administered as basal through urea, di-ammonium phosphate (DAP), and muriate of potash (MOP). The remaining nitrogen dose was applied in two equal portions during the tillering and panicle initiation stages of the crop. Zinc fertilizer was applied according to specific treatments, with the entire dose administered at the time of transplanting as a basal application.

**Soil Analysis:**

Soil samples were collected at harvest to assess post-treatment changes in fertility status. Parameters analyzed included: Soil pH and EC (using pH meter and conductivity meter) Jackson, 1973; Organic carbon (Walkley and Black method) Walkley and Black, 1934; Available N (Alkaline KMnO4 method) Subbiah and Asija, 1956; Available P (Olsen’s method) Olsen *et al*. 1954; Available K (Flame photometry) Hanway and Heidel, 1952; and Available Zn (DTPA extraction followed by AAS) Lindsay and Norvell, 1978. Initial soil analysis is shown in table 1.

**Table 1.** Initial physico-chemical properties of experimental soil.

|  |  |
| --- | --- |
| **Soil Properties** | **Value (Unit)** |
| Mechanical analysis |  |
| Sand (%) | 27.7 |
| Silt (%) | 54.1 |
| Clay (%) | 18.2 |
| Textural class | Silty loam |
| Physico-chemical properties |  |
| Bulk density (Mg m-3) | 1.39 Mg kg-1 |
| pH | 8.36 |
| EC | 0.34 dSm-1 |
| Organic Carbon | 3.65 g kg-1 |
| Available N | 170.1 kg ha-1 |
| Available P | 13.1 kg ha-1 |
| Available K | 270.8 kg ha-1 |
| Available Zn | 0.51 ppm |

## Statistical Analysis: Data were subjected to analysis of variance (ANOVA) using SPSS Statistics 21. Treatment means were compared using the least significant difference (LSD) test at a 5% level of significance (p < 0.05).

## RESULTS AND DISCUSSION

The data regarding effect of Zinc based fertilizer and biofertilizers (ZMB) on soil pH is given in Table 2. There was no significant difference have been observed with the application of treatments. The highest value of pH (8.34) was observed with T1: 100% RDF, and the lowest value (8.08) was observed with T7: RDF + 5.0 kg Zn ha-1(Zinc sulphate) + ZMB. electrical conductivity remained non-significant in between the treatments but there is slight decrease from initial level (0.34 dSm-1) to harvest (0.24 dSm-1). However, the lowest EC (0.24 dSm-1) at harvest recorded with T7: RDF +5.0 kg Zn ha-1 (Zinc sulphate) + ZMB and highest EC (0.34 dSm-1) was observed with T1: 100% RDF. The highest organic carbon (4.20 g kg-1) observed with T7: RDF +5.0 kg Zn ha-1 (Zinc sulphate) + ZMB, it was at par with T8, T6, T3 and T2 and the lower organic carbon (3.67g kg-1) was observed with T1: 100% RDF. Increased plant biomass produced by fertilizers results in increased returns of organic material to the soil in the form of decaying roots, litter, and crop residues. These results were also corroborated with the finding of Chandra *et al*. (2021) and Nath *et al*. (2019).

**Table 2.** Effect of Zinc-Based Fertilizer and Biofertilizer (ZMB) on Soil pH, Electrical Conductivity, and Organic Carbon.

|  |  |  |  |
| --- | --- | --- | --- |
| **Treatment** | **pH (1:2.5)** | **EC (dSm-1)** | **OC (g kg-1)** |
| T1: RDF 100% (150:60:40) | 8.34 | 0.34 | 3.67 |
| T2: RDF + 2.5 kg Zn ha-1 (Zinc Sulphate) | 8.21 | 0.29 | 3.97 |
| T3: RDF + 5.0 kg Zn ha-1 (Zinc Sulphate) | 8.17 | 0.27 | 4.02 |
| T4: RDF + 2.5 kg Zn ha-1 (Zinc Oxide) | 8.30 | 0.32 | 3.88 |
| T5: RDF + 5.0 kg Zn ha⁻¹ (Zinc Oxide) | 8.23 | 0.31 | 3.90 |
| T6: RDF + Biofertilizer (ZMB) | 8.16 | 0.26 | 4.06 |
| T7: RDF + 5.0 kg Zn ha-1 (Zinc Sulphate) + Biofertilizer (ZMB) | 8.08 | 0.24 | 4.14 |
| T8: RDF + 2.5 kg Zn ha-1 (Zinc Sulphate) + 2.5 kg Zn ha-1 (Zinc Oxide) + ZMB | 8.10 | 0.25 | 4.20 |
| **SEm ±** | 0.06 | 0.02 | 0.09 |
| **C.D. (P = 0.05)** | NS | NS | 0.27 |

**Figure 1.** Effect of ZMB on pH, EC, and OC.

Data regarding available nitrogen in soil after harvest of crop as affected by Zinc based fertilizer and ZMB given in Table 3. Data clearly showed that available nitrogen was influenced significantly by different Zinc based fertilizers. Maximum value (182.87 kg ha-1) was obtained with T7: RDF +5.0 kg Zn ha-1 (Zinc sulphate) + ZMB, which was significantly at par with T8 (181.90 kg ha-1), T6 (179.23 kg ha-1) and T3 (177.93 kg ha-1). This might be due to solubilization of others form of soil minerals and enhanced availability of nitrogen by the liquid biofertilizers. These finding confirms by Shahane *et al.* (2020). The maximum available phosphorus (15.10 kg ha-1) was observed with T7: RDF + 5.0 kg Zn ha-1 (Zinc sulphate) + ZMB. Treatment T8 and T6 were found to be at par with each other for the soil available P. These remaining five treatments were significantly superior over other treatments. This might be due to solubilization of bound form of soil minerals and enhanced availability of nutrients in the soil for plant growth and development by the liquid biofertilizers. The findings of this investigation are confirmed by Nath *et al.* (2019) and Nataraja *et al*. (2021).

**Table 3.** Effect of Zinc-Based Fertilizer and Biofertilizer (ZMB) on Available Nutrients (kg ha-1)

|  |  |  |  |
| --- | --- | --- | --- |
| **Treatment** | **N** | **P** | **K** |
| T1: RDF 100% (150:60:40) | 174.37 | 13.33 | 271.33 |
| T2: RDF + 2.5 kg Zn ha-1 (Zinc Sulphate) | 177.17 | 14.03 | 275.15 |
| T3: RDF + 5.0 kg Zn ha-1 (Zinc Sulphate) | 177.93 | 14.10 | 277.02 |
| T4: RDF + 2.5 kg Zn ha-1 (Zinc Oxide) | 175.27 | 13.68 | 273.57 |
| T5: RDF + 5.0 kg Zn ha⁻¹ (Zinc Oxide) | 176.10 | 13.87 | 274.33 |
| T6: RDF + Biofertilizer (ZMB) | 179.23 | 14.47 | 277.67 |
| T7: RDF + 5.0 kg Zn ha-1 (Zinc Sulphate) + Biofertilizer (ZMB) | 182.87 | 15.10 | 282.40 |
| T8: RDF + 2.5 kg Zn ha-1 (Zinc Sulphate) + 2.5 kg Zn ha-1 (Zinc Oxide) + ZMB | 181.90 | 14.77 | 279.53 |
| **SEm ±** | 1.76 | 0.33 | 1.90 |
| **C.D. (P=0.05)** | 5.14 | 0.96 | 5.55 |

Potassium content among soils under various treatments containing organic inputs with zinc and liquid biofertilizer were found to be significantly higher over other treatments. The maximum available potassium was observed with the application of T7: RDF +5.0 kg Zn ha-1 (Zinc sulphate) + ZMB, which was significantly at par with T8 (279.53 kg ha-1), T6 (277.67 kg ha-1) and T3 (277.02 kg ha-1) and minimum available potassium (271.33 kg ha-1) was observed with T1: 100% RDF followed by T4. The reason for this may be attributed to higher available potassium by the agency of more number of active nutrient mobilizing bacteria assumed to be present under present under such treatments. This might be due to solubilization of bound form of soil minerals and enhanced availability of nutrients in the soil by the liquid biofertilizer. These findings are confirmed by Shahane *et al*. (2020).

**Table 4.** Effect of Zinc-Based Fertilizer and ZMB on Available Zinc in Soil

|  |  |
| --- | --- |
| **Treatment** | **Zn (ppm)** |
| T1: RDF 100% (150:60:40) | 0.54 |
| T2: RDF + 2.5 kg Zn ha-1 (Zinc Sulphate) | 0.57 |
| T3: RDF + 5.0 kg Zn ha-1 (Zinc Sulphate) | 0.61 |
| T4: RDF + 2.5 kg Zn ha-1 (Zinc Oxide) | 0.59 |
| T5: RDF + 5.0 kg Zn ha⁻¹ (Zinc Oxide) | 0.63 |
| T6: RDF + Biofertilizer (ZMB) | 0.65 |
| T7: RDF + 5.0 kg Zn ha-1 (Zinc Sulphate) + Biofertilizer (ZMB) | 0.67 |
| T8: RDF + 2.5 kg Zn ha-1 (Zinc Sulphate) + 2.5 kg Zn ha-1 (Zinc Oxide) + ZMB | 0.71 |
| **SEm ±** | 0.02 |
| **C.D. (P=0.05)** | 0.05 |

Data regarding available zinc in soil after harvest of crop as affected by Zinc based fertilizer in combination with other nutrient management practices during the study are given in Table 4. The data revealed that the application of T8: RDF +2.5 kg Zn ha-1 (Zinc sulphate) + 2.5 kg Zn ha-1 (Zinc oxide) + ZMB, observed highest available zinc (0.71 ppm) content in soil which was significantly at par with T7: RDF +5.0 kg Zn ha-1 (Zinc Sulphate) + ZMB. The minimum available zinc (0.54 ppm) was observed in soil with T1: 100% RDF followed by T2: RDF + 2.5 kg Zn ha-1 (Zinc Sulphate). The data clearly indicated that the inoculation of zinc mobilizing bacteria effects on availability of Zn in soil. Zinc solubilizing bacteria for example *Bacillus sp*. produce organic acids viz., gluconic acid. Gluconic acid is a major anion which helps in solubilization of insoluble Zn compounds resulting increased the availability of Zn. These results were also corroborated with the finding of Dinesh *et al*. (2018).

## CONCLUSION

The application of RDF + 5.0 kg Zn ha-1 (Zinc Sulphate) + ZMB has non significantly effect on pH, Electrical Conductivity and also application of RDF + 5.0 kg Zn ha-1 (Zinc Sulphate) + ZMB has significantly influenced Organic carbon, Available N, P, K and Zn.

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