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Study on Nano-Zn, Inorganic, and Organic Nutrient Management Practices and Their Impact on Nutrient Availability in Kharif Maize (*Zea mays* L.)

Abstract

A study was conducted to assess the impact of Nano-Zn, inorganic, and organic nutrient management practices on the physico-chemical properties and nutrient availability in Kharif maize (*Zea mays* L.) grown during 2022 and 2023 at Chandra Shekhar Azad University of Agriculture & Technology, Kanpur. The experiment followed a split-plot design, with organic manures (Control, FYM at 10 t/ha, and Vermicompost at 5 t/ha) as the main plot treatments and various nutrient management strategies (Control, 75% RDF, 75% RDF + ZnSO₄ at 25 kg/ha, 75% RDF + Nano-Zn at 10 ml/litre, 100% RDF, 100% RDF + ZnSO₄, and 100% RDF + Nano-Zn) as the subplot treatments. Results showed that combining 100% RDF with Nano-Zn and ZnSO₄ significantly enhanced soil nutrient availability and improved physico-chemical properties compared to control treatments. The organic carbon content was highest in the 100% RDF + Nano-Zn treatment (0.492%), suggesting an increase in soil organic matter. Nitrogen availability was significantly higher in this treatment, with a pooled value of 151.167 kg/ha, compared to 143.443 kg/ha in the control. Phosphorus availability also increased in the 100% RDF + Nano-Zn treatment (16.337 kg/ha), indicating better phosphorus mobilization. Potassium availability was enhanced, with the highest recorded value (216.39 kg/ha) in the 100% RDF + Nano-Zn treatment, while the control treatment had 213.597 kg/ha. Zinc availability was markedly improved, with the 100% RDF + Nano-Zn treatment reaching 0.853 mg/kg, compared to 0.79 mg/kg in the control. This study demonstrated that integrating Nano-Zn and ZnSO₄ with inorganic fertilizers significantly improved soil fertility, nutrient availability, and potentially enhanced crop performance in Kharif maize. These findings indicate that combining inorganic and nano-fertilizers could be an effective nutrient management strategy, contributing to sustainable agricultural practices and improved productivity in maize cultivation, alongside better soil health.

Keywords: *Nano-Zn, Organic manures, Nutrient management, Soil fertility, Nutrient availability*

Introduction

Maize (*Zea mays* L.) is a highly significant cereal crop worldwide, valued for its versatility as food, feed, and a key industrial raw material. In India, maize is cultivated in both the kharif and rabi seasons, with kharif maize playing a crucial role in the country's overall maize production [1]. One of the major challenges to achieving optimal productivity is the issue of nutrient deficiencies, particularly in areas where soil fertility is low. Thus, effective nutrient management is essential for sustaining crop growth, boosting yield, and improving nutrient availability within the soil. On a global scale, maize is grown over an area of approximately 207.25 million hectares in 160 countries, producing a total of 1,217.30 million tonnes with an average yield of 5.87 metric tonnes per hectare (USDA, 2021-22). In India, maize holds its place as the third most important cereal crop after rice and wheat, cultivated over 10.10 million hectares, with a production of 33.60 million tonnes and an average yield of 3.33 metric tonnes per hectare [2]. In Uttar Pradesh alone, maize occupies 0.73 million hectares, yielding 1.53 million tonnes at a productivity rate of 2,095.8 kg per hectare [3].

In recent years, there has been growing interest in the application of nano-fertilizers as a more sustainable and efficient alternative to traditional fertilizers. Among these, Nano-Zinc (Nano-Zn) has gained significant attention due to its enhanced reactivity, controlled release, and potential to improve nutrient uptake in plants. Zinc, as an essential micronutrient, plays a vital role in numerous physiological processes in plants, including enzyme activation, protein synthesis, and growth regulation. However, zinc deficiency is a prevalent issue in maize cultivation, particularly in zinc-deficient soils, where it adversely impacts both yield and nutrient content [4]. The integration of nano-fertilizers with conventional inorganic and organic nutrient management practices represents a promising approach for addressing such deficiencies while enhancing nutrient use efficiency. Although inorganic fertilizers are widely used, they often lead to nutrient losses through processes like leaching and volatilization, which can diminish crop productivity and contribute to environmental damage. In contrast, organic nutrient sources such as composts and manures improve soil health by fostering microbial activity, increasing organic matter, and gradually enhancing nutrient availability. The combination of these strategies-nano-Zn, inorganic, and organic fertilizers-offers the potential for a synergistic effect, which could improve nutrient availability and help maintain soil fertility.

Material and Methods

The experiment took place during the years 2022 and 2023 at the Students' Instructional Farm, Department of Agronomy, Chandra Shekhar Azad University of Agriculture & Technology, Kanpur. A Split-Plot Design was employed, with organic manures assigned to the main plots and nutrient management practices to the sub-plots. The experimental site is located between 25°26' to 26°58' North latitude and 79°31' to 81°34' East longitude, at an elevation of 125.9 meters above sea level, within the alluvial Indo-Gangetic Plain zone of central Uttar Pradesh. The soil of the site was classified as silt loam, with sand content recorded at 24.86% (2022) and 24.88% (2023), silt at 53.94% and 53.97%, and clay at 21.20% and 21.19%. The particle density was 2.56 Mg/m³ (2022) and 2.55 Mg/m³ (2023), while bulk density was 1.37 Mg/m³ and 1.36 Mg/m³, respectively. The soil pH values were 7.72 (2022) and 7.67 (2023), with organic carbon contents of 0.43% and 0.44%. Electrical conductivity was measured at 5.4 dSm⁻¹ (2022) and 5.3 dSm⁻¹ (2023). Available nitrogen levels were 135.40 kg/ha and 138.25 kg/ha, available phosphorus (P₂O₅) was 13.50 kg/ha and 14.28 kg/ha, potassium (K₂O) was 210.45 kg/ha and 214.25 kg/ha, and zinc was 77.01 g/ha and 78.32 g/ha, respectively. The region experiences a sub-tropical climate, with an annual rainfall averaging around 890 mm, most of which is received from mid-June to September. The crop growing seasons were marked by cold, dry winters with occasional frost, and variable meteorological conditions were observed during both years. Mean weekly maximum and minimum temperatures ranged from 29.3°C to 37.7°C and 16.0°C to 28.5°C in 2022, and from 31.4°C to 35.6°C and 14.5°C to 28.9°C in 2023.

The main plot treatments consisted of three organic manure applications: control (O1), FYM at 10 t/ha (O2), and vermicompost at 5 t/ha (O3). In the sub-plots, seven nutrient management treatments were evaluated: control (M1), 75% RDF (120:60:60 NPK kg/ha) (M2), 75% RDF + ZnSO₄ at 25 kg/ha (M3), 75% RDF + Nano-Zinc at 10 ml/litre (M4), 100% RDF (M5), 100% RDF + ZnSO₄ at 25 kg/ha (M6), and 100% RDF + Nano-Zinc at 10 ml/litre (M7). The maize variety used in the study was DKC (DEKALB)-9144, a full maturity hybrid from Bayer

Crop Science Ltd., known for its adaptability to both rainfed and irrigated conditions, with a yield potential of 74-86 q/ha and a maturity period of 105-115 days.

The soil properties were estimated using standard scientific procedures. Bulk density was measured using the core method as described by [5]. Particle density was estimated using the pycnometer method outlined by [6]. Soil pH was determined with a pH meter in a 1:2.5 soil-water suspension, following the method of [7]. Electrical conductivity (EC) was assessed with an EC meter in a 1:2 soil-water extract according to the procedure by [8]. Cation exchange capacity (CEC) was measured using the ammonium acetate extraction method as outlined by [9]. Organic carbon (OC) was determined using the wet oxidation method described by [10]. Available nitrogen (N) was estimated by the alkaline permanganate method according to [11]. Available phosphorus (P) was measured using the Olsen method developed by [12]. Available potassium (K) was determined by the flame photometer method according to [13]. Available zinc (Zn) was estimated using the diethylene triamine pentaacetic acid (DTPA) extraction method described by [14].

Result and Discussion

1. Available Physico-chemical properties

The study on Nano-Zn, inorganic, and organic nutrient management practices on the physico-chemical properties of kharif maize during 2022 and 2023 demonstrated (Table 1) minimal variations across treatments in bulk density, particle density, soil pH, electrical conductivity, and cation exchange capacity (CEC). Bulk density ranged from 1.370 Mg/m³ in the 100% RDF treatment to 1.380 Mg/m³ in the control treatment, with no significant differences observed between treatments or years. Particle density varied slightly, with values ranging from 2.547 Mg/m³ in the control treatment to 2.607 Mg/m³ in the 100% RDF + Nano-Zn treatment, though these differences were also not statistically significant. Soil pH remained relatively stable across treatments, with values ranging from 7.467 in the 100% RDF + ZnSO₄ treatment to 7.671 in the control, indicating that nutrient management practices did not significantly affect soil pH, which remained slightly alkaline. Electrical conductivity (EC) showed no significant changes, with values between 5.573 dSm⁻¹ in the control and 5.587 dSm⁻¹ in the 100% RDF + Nano-Zn treatment, reflecting stable salinity levels. The CEC values, however, showed some improvement with the 100% RDF + Nano-Zn treatment, which had the highest CEC value of 48.157 cmol/kg, compared to the control treatment's 44.307 cmol/kg, indicating a slightly enhanced nutrient-holding capacity in treatments involving Nano-Zn and ZnSO₄. Despite these minor improvements in CEC, the overall impact of different nutrient management practices on the physico-chemical properties of the soil was minimal across both years [15], [16], [17].

2. Available Nutrients

The study on Nano-Zn, inorganic, and organic nutrient management practices in kharif maize revealed that treatments (Table 2) involving 100% RDF combined with Nano-Zn and ZnSO₄ significantly improved the availability of key nutrients such as nitrogen (N), phosphorus (P), potassium (K), and zinc (Zn) in the soil. Organic carbon (OC) content was highest in the 100% RDF + Nano-Zn treatment (0.492%), indicating enhanced organic matter. Similarly, nitrogen availability was highest in the same treatment, with a pooled value of 151.167 kg/ha, compared to 143.443 kg/ha in the control, showing that the combination of inorganic and Nano-Zn fertilizers enhanced nitrogen levels in the soil. Phosphorus availability also followed this

pattern, with the 100% RDF + Nano-Zn treatment recording the highest phosphorus levels (16.337 kg/ha), while the control was significantly lower. Potassium availability was also elevated in the RDF treatments, with 216.39 kg/ha in the 100% RDF + Nano-Zn treatment compared to 213.597 kg/ha in the control. Zinc availability showed the most significant increase in the treatments involving ZnSO₄ and Nano-Zn, with the 100% RDF + Nano-Zn treatment yielding 0.853 mg/kg, significantly higher than the control at 0.79 mg/kg. These results indicate that the application of Nano-Zn and ZnSO₄ in combination with full doses of inorganic fertilizers substantially improves soil nutrient availability, enhancing soil fertility and supporting better crop growth and yield in kharif maize [18], [19], [20].

UNDER PEER REVIEW

Table: 2 Studies of Nano- Zn, inorganic and organic nutrient management practices on Available Nutrient in *kharif* Maize

| Treatment | Available OC (%) | | | Available N (Kg/ha) | | | Available P (Kg/ha) | | | Available K (Kg/ha) | | | Available Zn (mg/kg) | | |
|--|------------------|--------------|--------------|---------------------|--------------|--------------|---------------------|--------------|--------------|---------------------|--------------|--------------|----------------------|--------------|--------------|
| | 2022 | 2023 | Pooled | 2022 | 2023 | Pooled | 2022 | 2023 | Pooled | 2022 | 2023 | Pooled | 2022 | 2023 | Pooled |
| Organic Manures (Main plot) | | | | | | | | | | | | | | | |
| Control | 0.471 | 0.471 | 0.471 | 147.254 | 144.521 | 145.888 | 15.474 | 15.477 | 15.476 | 213.467 | 214.749 | 214.108 | 0.796 | 0.809 | 0.802 |
| FYM -10 t/ha | 0.481 | 0.489 | 0.485 | 148.933 | 148.571 | 148.752 | 15.953 | 15.903 | 15.928 | 215.104 | 215.921 | 215.513 | 0.827 | 0.837 | 0.832 |
| Vermi Compost-5 t/ha | 0.487 | 0.494 | 0.491 | 149.780 | 149.403 | 149.591 | 16.029 | 16.174 | 16.101 | 215.310 | 216.190 | 215.750 | 0.834 | 0.844 | 0.839 |
| SE(d) ± | 0.004 | 0.004 | 0.004 | 1.258 | 1.286 | 1.272 | 0.140 | 0.140 | 0.140 | 1.801 | 1.802 | 1.796 | 0.007 | 0.007 | 0.007 |
| CD (P=0.05) | 0.012 | 0.012 | 0.012 | NS | 3.667 | NS | 0.395 | 0.400 | 0.398 | NS | NS | NS | 0.020 | 0.021 | 0.021 |
| Nutrient Management (Sub plot) | | | | | | | | | | | | | | | |
| Control | 0.47 | 0.47 | 0.47 | 145.85 | 141.037 | 143.443 | 15.193 | 15.197 | 15.195 | 212.927 | 214.267 | 213.597 | 0.78 | 0.8 | 0.79 |
| 75 % RDF (@120:60:60 NPK kg/ha) | 0.48 | 0.48 | 0.48 | 147.52 | 145.12 | 146.32 | 15.637 | 15.643 | 15.64 | 213.827 | 214.493 | 214.16 | 0.8 | 0.81 | 0.805 |
| 75 % RDF + ZnSO ₄ (@ 25 kg/ha) | 0.477 | 0.483 | 0.48 | 148.46 | 146.727 | 147.593 | 15.763 | 15.657 | 15.71 | 214.577 | 215.597 | 215.087 | 0.813 | 0.827 | 0.82 |
| 75 % RDF + Nano- Zinc -(@ 10 ml/litre) | 0.477 | 0.48 | 0.478 | 148.947 | 147.673 | 148.31 | 15.787 | 15.71 | 15.748 | 214.67 | 215.633 | 215.152 | 0.82 | 0.827 | 0.823 |
| 100 % RDF (@120:60:60 NPK kg/ha) | 0.483 | 0.49 | 0.487 | 149.133 | 149.333 | 149.233 | 15.99 | 15.993 | 15.992 | 215.06 | 215.723 | 215.392 | 0.833 | 0.833 | 0.833 |
| 100 % RDF + ZnSO ₄ (@ 25 kg/ha) | 0.487 | 0.493 | 0.49 | 150.177 | 150.77 | 150.473 | 16.157 | 16.29 | 16.223 | 215.647 | 216.53 | 216.088 | 0.84 | 0.853 | 0.847 |
| 100 % RDF + Nano- Zinc - (@ 10 ml/litre) | 0.487 | 0.497 | 0.492 | 150.503 | 151.83 | 151.167 | 16.203 | 16.47 | 16.337 | 215.683 | 217.097 | 216.39 | 0.847 | 0.86 | 0.853 |
| SE(d) ± | 0.014 | 0.014 | 0.014 | 4.422 | 4.396 | 4.409 | 0.472 | 0.472 | 0.472 | 6.383 | 6.409 | 6.396 | 0.024 | 0.025 | 0.025 |

| | | | | | | | | | | | | | | | |
|----------------------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|---------------|---------------|---------------|--------------|--------------|--------------|
| CD (P=0.05) | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |
| Interaction (A x B) | | | | | | | | | | | | | | | |
| SE(d) ± | 0.023 | 0.024 | 0.023 | 7.202 | 7.165 | 7.183 | 0.769 | 0.769 | 0.769 | 10.393 | 10.434 | 10.413 | 0.040 | 0.040 | 0.040 |
| CD (P=0.05) | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS | NS |

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Conclusion

The application of 100% RDF, when combined with Nano-Zn and ZnSO₄, significantly improved the availability of key soil nutrients, including nitrogen, phosphorus, potassium, and zinc. These treatments resulted in increased organic carbon content, enhanced nitrogen levels, more efficient phosphorus mobilization, improved potassium availability, and substantial enrichment of zinc in the soil compared to the control. The integration of inorganic fertilizers with Nano-Zn and ZnSO₄ proved to be an effective approach for enhancing soil fertility, promoting better nutrient uptake, and potentially increasing crop yields in kharif maize. Incorporating Nano-Zn and ZnSO₄ into conventional nutrient management practices presents a promising strategy for sustainable agriculture, leading to improved soil health and higher crop productivity.

Disclaimer (Artificial intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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