Evaluation of Nano-Zn, Inorganic, and Organic Nutrient Management Strategies and Their Effects on Growth Indices in Kharif Maize (*Zea mays* L.)

Abstract

This study, conducted during the Kharif seasons of 2022 and 2023 at the Students' Instructional Farm, Department of Agronomy, Chandra Shekhar Azad University of Agriculture & Technology, Kanpur, aimed to evaluate the effects of Nano-Zn, inorganic, and organic nutrient management practices on Kharif maize growth and yield. A split-plot design with three replications was employed, where organic manures (control, FYM at 10 t/ha, and vermicompost at 5 t/ha) were assigned to the main plots, and nutrient management practices (control, 75% RDF, 75% RDF + $ZnSO_4$, 75% RDF + Nano-Zn, 100% RDF, 100% RDF + $ZnSO_4$, and 100% RDF + Nano-Zn) were allocated to the sub-plots. The maize variety used was DKC-9144 was used. The soil was sandy loam with a pH of 7.72-7.67, bulk density of 1.37 Mg/m^3, and organic carbon content of 0.43%-0.44%. The experimental site falls within the Indo-Gangetic Plain, experiencing a subtropical climate with an annual rainfall of around 890 mm. Data collected on crop growth rate (CGR), relative growth rate (RGR), and absolute growth rate (AGR) across various growth stages (30-60 DAS, 60-90 DAS, and from 90 DAS to harvest) showed that the 100% RDF + Nano-Zn at 10 ml/litre treatment resulted in the highest growth rates, followed by 100% RDF + $ZnSO_4$. Vermicompost at 5 t/ha outperformed FYM, highlighting the beneficial impact of both organic and advanced nutrient management practices, especially the use of Nano-Zn, on maize productivity and growth.

Keywords: *Nano-Zinc, Vermicompost, FYM, Nutrient, Maize*

Introduction

Maize (*Zea mays* L.), commonly known as corn, is one of the most important cereal crops cultivated globally and is a staple food in many parts of the world. In India, it plays a significant role in the agricultural economy, especially during the Kharif season, when it is cultivated under rainfed conditions. However, maize productivity is often constrained by inadequate soil fertility and nutrient management practices. With the growing demand for sustainable agricultural practices, enhancing crop productivity while maintaining soil health has become a primary focus for agronomists and researchers alike [1]. Maize is cultivated on a global scale, covering approximately 207.25 million hectares across 160 countries, yielding 1,217.30 million tonnes of production with an average yield of 5.87 metric tonnes per hectare [2]. In India, maize ranks as the third most important cereal crop after rice and wheat, grown on 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 is cultivated on 0.73 million hectares, producing 1.53 million tonnes with a productivity rate of 2,095.8 kg per hectare [3].

The efficient management of nutrients is crucial for improving the growth and yield of Kharif maize. Nutrient management practices can be broadly classified into three categories: inorganic, organic, and nano-fertilizers. Inorganic fertilizers, such as NPK (Nitrogen, Phosphorus, and Potassium) and Zn Sulphate, have been widely used in conventional agriculture for their ability to provide essential macronutrients and micronutrients for plant growth. However, excessive use of inorganic fertilizers can lead to soil degradation and environmental pollution. On the other hand, organic nutrient sources such as farmyard manure (FYM) and vermicompost offer a more sustainable alternative [4]. These organic materials improve soil structure, increase microbial activity, and provide a slow release of nutrients, contributing to long-term soil health.

In recent years, nano-technology has emerged as a promising tool in agriculture, offering innovative solutions for nutrient management. Nano-Zn, a nano-formulation of zinc, is one such advancement that aims to enhance the availability and uptake of zinc, an essential micronutrient for crop growth. Zinc plays a pivotal role in enzyme activation, protein synthesis, and the production of growth hormones in plants [5]. The use of nano-Zn can potentially improve nutrient use efficiency and reduce the quantities of fertilizers required, thereby minimizing the environmental footprint of agricultural practices. The combined use of inorganic, organic, and nano-fertilizers represents a synergistic approach to nutrient management [6]. Integrating these nutrient sources can potentially enhance soil fertility, improve nutrient uptake, and increase maize growth indices such as plant height, leaf area, chlorophyll content, and biomass accumulation. However, the impact of different combinations of these nutrient management strategies on maize growth under Kharif conditions remains underexplored.

Material and Methods

The experiment was carried out during the years 2022 and 2023 at the Students' Instructional Farm, under the Department of Agronomy at Chandra Shekhar Azad University of Agriculture & Technology, Kanpur. A split-plot design was implemented, where organic manures were assigned to the main plots, and various nutrient management practices were assigned to the sub-plots. The geographical coordinates of the experimental site lie between 25°26' to 26°58' North latitude and 79°31' to 31°34' East longitude, situated at an altitude of 125.9 meters above sea level, within the alluvial Indo-Gangetic Plain region of central Uttar Pradesh. The soil texture was classified as silt loam, with sand content measuring 24.86% in 2022 and 24.88% in 2023, silt content at 53.94% and 53.97%, and clay content at 21.20% and 21.19%, respectively. The particle density was recorded as 2.56 Mg/m^3 in 2022 and 2.55 Mg/m^3 in 2023, with bulk densities of 1.37 Mg/m^3 and 1.36 Mg/m^3, respectively. The soil pH was slightly alkaline, measuring 7.72 in 2022 and 7.67 in 2023, and the organic carbon content was 0.43% in 2022 and 0.44% in 2023. Electrical conductivity was found to be 5.4 dSm^{-1} in 2022 and 5.3 dSm^{-1} in 2023. The available nitrogen content was 135.40 kg/ha and 138.25 kg/ha in the respective years, with phosphorus (P_2O_5) levels of 13.50 kg/ha and 14.28 kg/ha, potassium (K_2O) levels of 210.45 kg/ha and 214.25 kg/ha, and zinc levels of 77.01 g/ha and 78.32 g/ha. The region is characterized by a sub-tropical climate, with an average annual rainfall of approximately 890 mm, predominantly occurring from mid-June to September. During the crop-growing period, the seasons were marked by cold and dry winters, with occasional frost. Meteorological data indicated variations in mean weekly maximum and minimum temperatures, ranging from 29.3°C to 37.7°C and 16.0°C to 28.5°C in 2022, and 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), farmyard manure (FYM) at 10 t/ha (O2), and vermicompost at 5 t/ha (O3). The sub-plots involved seven different nutrient management treatments: control (M1), 75% recommended dose of fertilizer (RDF) at 120:60:60 NPK kg/ha (M2), 75% RDF +

$ZnSO_4$ at 25 kg/ha (M3), 75% RDF + Nano-Zinc at 10 ml/liter (M4), 100% RDF (M5), 100% RDF + $ZnSO_4$ at 25 kg/ha (M6), and 100% RDF + Nano-Zinc at 10 ml/liter (M7). The maize variety used in this experiment was DKC (DEKALB)-9144, a full maturity hybrid from Bayer Crop Science Ltd., which is suitable for both rainfed and irrigated conditions, with a yield potential of 74-86 q/ha and a maturity duration of 105-115 days. The estimation of Crop Growth Rate (CGR), Relative Growth Rate (RGR), and Absolute Growth Rate (AGR) for maize during the stages of 30-60 DAS, 60-90 DAS, and 90 DAS to harvest was carried out by collecting plant dry matter at each interval. CGR was calculated using the formula: CGR = (W2 - W1) / (T2 - T1), where W1 and W2 represent the dry weights at times T1 and T2, respectively. RGR was determined using the formula: RGR = (ln W2 - ln W1) / (T2 - T1), where W1 and W2 are the dry weights of plants at times T1 and T2. AGR was estimated by using the formula: AGR = (W2 - W1) / (T2 - T1), reflecting the actual increase in biomass over time. These growth parameters were measured to assess the effect of nutrient treatments on maize performance.

Result and Discussion

Crop Growth Rate

The results presented in (Table 1) illustrate the significant effects of Nano-Zn, inorganic, and organic nutrient management practices on the Crop Growth Rate (CGR) of Kharif maize during different growth stages in the 2022 and 2023 seasons. The organic manure treatments showed that vermicompost at 5 t/ha produced the highest CGR across all stages, with pooled values of 0.645 g/m²/day at 30-60 DAS, 0.570 g/m²/day at 60-90 DAS, and 0.263 g/m²/day from 90 DAS to harvest, outperforming both FYM and the control. FYM at 10 t/ha also improved growth compared to the control, indicating the beneficial effects of organic matter in enhancing soil fertility. Among the nutrient management treatments, 100% RDF combined with Nano-Zn at 10 ml/litre significantly outperformed other treatments, with pooled CGR values of 0.696 g/m²/day at 30-60 DAS, 0.582 g/m²/day at 60-90 DAS, and 0.287 g/m²/day from 90 DAS to harvest, demonstrating the superior efficiency of Nano-Zn in promoting nutrient uptake and growth. The next best performance was observed with 100% RDF + ZnSO4 at 25 kg/ha, with pooled values of 0.678 g/m²/day at 30-60 DAS and 0.574 g/m²/day at 60-90 DAS, showing that conventional ZnSO4 application also contributed positively to crop growth, though it was less effective than Nano-Zn. Control treatments consistently resulted in the lowest CGR, underscoring the critical role of nutrient supplementation in achieving optimal maize growth. Although both organic and inorganic nutrient management practices independently impacted growth, no significant interactions between them were observed. The study highlights that 100% RDF with Nano-Zn at 10 ml/litre was the most effective treatment for enhancing maize growth, and vermicompost at 5 t/ha proved to be the best organic manure for improving CGR, emphasizing the importance of integrated nutrient management in maximizing maize productivity [7], [8], [9], [10].

Relative Growth Rate

The results presented in the (Table 2) on the relative growth rate (RGR) of Kharif maize under different organic and inorganic nutrient management practices show noticeable trends across the two years of study, 2022 and 2023. Among the organic manure treatments, vermicompost at 5 t/ha consistently demonstrated slightly higher RGR values compared to the control and FYM treatments, although the differences between FYM and vermicompost were minimal. For instance, the pooled RGR at 30-60 DAS for vermicompost was 0.034 g/g/day, which was slightly higher than the control (0.032 g/g/day). This trend continued through the 60-90 DAS stage and from 90 DAS until harvest, where vermicompost and FYM produced higher RGR values than the control, highlighting the positive impact of organic manure on plant growth. Regarding the nutrient management treatments, 100% RDF combined with Nano-Zn at 10 ml/litre yielded the highest RGR values across all growth stages, with a pooled RGR of 0.035 g/g/day at 30-60 DAS, 0.008 g/g/day at 60-90 DAS, and 0.003 g/g/day from 90 DAS to harvest, outperforming all other treatments. The next best performer was 100% RDF + ZnSO4 at 25 kg/ha, showing that zinc supplementation whether in its nano or conventional form-enhanced growth over the control and 75% RDF treatments. The control treatments, both for organic manures and nutrient management, consistently recorded the lowest RGR values, particularly in the later growth stages, indicating the necessity of nutrient supplementation for optimal maize growth. While there were some variations between treatments, the application of 100% RDF with Nano-Zn was the most effective strategy for maximizing the relative growth rate of Kharif maize [11], [12], [13], [14].

Absolute Growth Rate

The results of the study on the absolute growth rate (AGR) of Kharif maize reveal a significant impact of Nano-Zn, inorganic, and organic nutrient management practices during the 2022 and 2023 seasons (Table 3). Among the organic manure treatments, vermicompost at 5 t/ha consistently resulted in the highest AGR across all growth stages, with pooled values of 4.302 g/plant/day at 30-60 DAS, 3.797 g/plant/day at 60-90 DAS, and 1.753 g/plant/day from 90 DAS to harvest, outperforming the control and FYM treatments. FYM at 10 t/ha also significantly improved the AGR compared to the control, highlighting the positive effects of organic amendments on crop growth. In the case of nutrient management, 100% RDF combined with Nano-Zn at 10 ml/litre emerged as the most effective treatment, producing the highest AGR values, with pooled rates of 4.641 g/plant/day at 30-60 DAS, 3.882 g/plant/day at 60-90 DAS, and 1.916 g/plant/day from 90 DAS to harvest. This was followed by the treatment of 100% RDF + $ZnSO_4$ at 25 kg/ha, which also showed notable improvements in AGR, indicating the beneficial role of zinc supplementation, particularly in its nano form, in enhancing plant growth. Control treatments, both for organic manure and nutrient management, consistently resulted in the lowest AGR, especially during the later stages of growth, underscoring the critical importance of nutrient inputs for optimal crop performance. No significant interactions were observed between organic and nutrient management practices. The application of 100% RDF with Nano-Zn at 10 ml/litre proved to be the most effective for maximizing maize growth, followed closely by the combination of 100% RDF and $ZnSO_4$, while vermicompost was the most beneficial organic manure [15], [16], [17].

Table 1: Studies of Nano- Zn, inorganic and organic nutrient management practices on Crop Growth rate ($g/m^2/day$) of *kharif* Maize

Treatment	Crop Growth Rate at 30-60 DAS			Crop Growth Rate at 60-90 DAS			Crop Growth Rate 90 DAS - at Harvest		
	2022	2023	Pooled	2022	2023	Pooled	2022	2023	Pooled
Organic Manures (Main plot)									

Control	0.476	0.491	0.484	0.533	0.523	0.528	0.195	0.206	0.201
FYM -10 t/ha	0.598	0.613	0.605	0.567	0.560	0.564	0.259	0.270	0.264
Vermi Compost- 5 t/ha	0.637	0.654	0.645	0.575	0.565	0.570	0.258	0.268	0.263
SE(d) ±	**0.007**	**0.007**	**0.007**	**0.005**	**0.005**	**0.005**	**0.004**	**0.004**	**0.004**
CD (P=0.05)	**0.019**	**0.019**	**0.019**	**0.014**	**0.014**	**0.014**	**0.010**	**0.010**	**0.010**
Nutrient Management (Sub plot)									
Control	0.425	0.44	0.433	0.527	0.517	0.522	0.108	0.122	0.115
75 % RDF (@120:60:60 NPK kg/ha)	0.49	0.502	0.496	0.537	0.53	0.534	0.212	0.227	0.219
75 % RDF + $ZnSO_4$ (@ 25 kg/ha)	0.549	0.564	0.556	0.551	0.543	0.547	0.256	0.268	0.262
75 % RDF + Nano-Zinc -(@ 10 ml/litre)	0.567	0.584	0.576	0.553	0.541	0.547	0.259	0.278	0.269
100 % RDF (@120:60:60 NPK kg/ha)	0.605	0.619	0.612	0.573	0.566	0.569	0.258	0.264	0.261
100 % RDF + $ZnSO_4$ (@ 25 kg/ha)	0.669	0.687	0.678	0.578	0.569	0.574	0.281	0.289	0.285
100 % RDF + Nano-Zinc - (@ 10 ml/litre)	0.687	0.706	0.696	0.587	0.578	0.582	0.286	0.289	0.287
SE(d) ±	**0.017**	**0.018**	**0.018**	**0.017**	**0.016**	**0.017**	**0.010**	**0.008**	**0.008**
CD (P=0.05)	**0.036**	**0.037**	**0.036**	**0.034**	**0.033**	**0.034**	**0.015**	**0.016**	**0.016**
Interaction (A x B)									
SE(d) ±	**0.029**	**0.030**	**0.029**	**0.027**	**0.027**	**0.027**	**0.013**	**0.013**	**0.013**
CD (P=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
Interaction (B x A)									
SE(d) ±	**0.030**	**0.031**	**0.031**	**0.029**	**0.028**	**0.029**	**0.013**	**0.014**	**0.013**
CD (P=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

Table 2: Studies of Nano- Zn, inorganic and organic nutrient management practices on Relative Growth rate (g/g/day) of *kharif* Maize

Treatments	**Relative Growth Rate at 30-60 DAS**			**Relative Growth Rate at 60-90 DAS**			**Relative Growth Rate 90 DAS – at Harvest**		
	2022	**2023**	**Pooled**	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
Organic Manures (Main plot)									
Control	0.032	0.032	0.032	0.010	0.010	0.010	0.002	0.002	0.002
FYM -10 t/ha	0.034	0.034	0.034	0.009	0.009	0.009	0.003	0.003	0.003

Vermi Compost- 5 t/ha	0.034	0.035	0.034	0.009	0.009	0.009	0.003	0.003	0.003
SE(d) ±	0.000	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
CD (P=0.05)	**0.001**	**0.001**	**0.001**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
Nutrient Management (Sub plot)									
Control	0.031	0.031	0.031	0.011	0.01	0.011	0.001	0.002	0.002
75 % RDF (@120:60:60 NPK kg/ha)	0.032	0.033	0.032	0.01	0.01	0.01	0.003	0.003	0.003
75 % RDF + $ZnSO_4$ (@ 25 kg/ha)	0.033	0.033	0.033	0.009	0.009	0.009	0.003	0.003	0.003
75 % RDF + Nano-Zinc -(@ 10 ml/litre)	0.033	0.034	0.034	0.009	0.009	0.009	0.003	0.003	0.003
100 % RDF (@120:60:60 NPK kg/ha)	0.034	0.034	0.034	0.009	0.009	0.009	0.003	0.003	0.003
100 % RDF + $ZnSO_4$ (@ 25 kg/ha)	0.035	0.035	0.035	0.008	0.008	0.008	0.003	0.003	0.003
100 % RDF + Nano-Zinc - (@ 10 ml/litre)	0.035	0.035	0.035	0.008	0.008	0.008	0.003	0.003	0.003
SE(d) ±	0.001	**0.001**	**0.001**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
CD (P=0.05)	**0.002**	**0.002**	**0.002**	**0.001**	**0.001**	**0.001**	**0.000**	**0.000**	**0.000**
Interaction (A x B)									
SE(d) ±	**0.002**	**0.002**	**0.002**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
CD (P=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
Interaction (B x A)									
SE(d) ±	**0.002**	**0.002**	**0.002**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**	**0.000**
CD (P=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

Table 3: Studies of Nano- Zn, inorganic and organic nutrient management practices on Absolute Growth rate (g/plant/day) of *kharif* Maize

Treatment	**Absolute Growth Rate at 30-60 DAS**			**Absolute Growth Rate at 60-90 DAS**			**Absolute Growth Rate 90 DAS- at Harvest**		
	2022	**2023**	**Pooled**	**2022**	**2023**	**Pooled**	**2022**	**2023**	**Pooled**
Organic Manures (Main plot)									
Control	3.176	3.273	3.225	3.550	3.484	3.517	1.298	1.376	1.337
FYM -10 t/ha	3.985	4.084	4.034	3.780	3.736	3.758	1.728	1.797	1.763

Vermi Compost- 5 t/ha	4.244	4.360	4.302	3.831	3.764	3.797	1.718	1.788	1.753
SE(d) ±	**0.044**	**0.045**	**0.044**	**0.034**	**0.033**	**0.034**	**0.023**	**0.024**	**0.024**
CD (P=0.05)	**0.125**	**0.128**	**0.126**	**0.096**	**0.095**	**0.096**	**0.067**	**0.068**	**0.067**
Nutrient Management (Sub plot)									
Control	2.836	2.931	2.883	3.516	3.449	3.482	0.722	0.811	0.767
75 % RDF (@120:60:60 NPK kg/ha)	3.265	3.349	3.307	3.582	3.532	3.557	1.411	1.515	1.463
75 % RDF + $ZnSO_4$ (@ 25 kg/ha)	3.656	3.757	3.707	3.672	3.619	3.645	1.704	1.785	1.744
75 % RDF + Nano- Zinc - (@ 10 ml/litre)	3.782	3.891	3.836	3.688	3.606	3.647	1.729	1.853	1.791
100 % RDF (@120:60:60 NPK kg/ha)	4.033	4.127	4.08	3.817	3.774	3.796	1.717	1.759	1.738
100 % RDF + $ZnSO_4$ (@ 25 kg/ha)	4.462	4.58	4.521	3.856	3.796	3.826	1.876	1.93	1.903
100 % RDF + Nano- Zinc - (@ 10 ml/litre)	4.577	4.706	4.641	3.911	3.852	3.882	1.908	1.924	1.916
SE(d) ±	**0.117**	**0.120**	**0.118**	**0.111**	**0.110**	**0.110**	**0.050**	**0.052**	**0.051**
CD (P=0.05)	**0.237**	**0.244**	**0.240**	**0.227**	**0.223**	**0.225**	**0.102**	**0.106**	**0.104**
Interaction (A x B)									
SE(d) ±	**0.192**	**0.197**	**0.194**	**0.182**	**0.179**	**0.180**	**0.084**	**0.087**	**0.085**
CD (P=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**
Interaction (B x A)									
SE(d) ±	**0.202**	**0.207**	**0.205**	**0.193**	**0.190**	**0.191**	**0.087**	**0.090**	**0.088**
CD (P=0.05)	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**	**NS**

Conclusion

The study concludes that nutrient management practices significantly impact the growth and development of Kharif maize, with the combined application of 100% recommended dose of fertilizer (RDF) and Nano-Zn at 10 ml/litre yielding the highest crop growth and absolute growth rates across all stages. The inclusion of zinc in both its nano and conventional forms enhanced growth performance, though Nano-Zn proved to be more effective. Organic manure treatments, particularly vermicompost at 5 t/ha, also contributed positively to growth, outperforming FYM and control treatments. The control treatments exhibited the lowest growth rates, underscoring the importance of proper nutrient supplementation. Overall, the study highlights the benefits of integrating organic manures and advanced nutrient management practices, especially the use of Nano-Zn, for maximizing maize productivity and ensuring optimal plant growth.

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