



International Journal of Research in Agronomy

E-ISSN: 2618-0618
P-ISSN: 2618-060X
© Agronomy
NAAS Rating (2026): 5.20
www.agronomyjournals.com
2026; 9(5): 561-564
Received: 08-02-2026
Accepted: 16-03-2026

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Effect of zinc–copper nanofertilizer on soil microbial population in maize production

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DOI: <https://www.doi.org/10.33545/2618060X.2026.v9.i5h.5566>

Abstract

A two-year field investigation was conducted during kharif 2023 and 2024 at Rajasthan College of Agriculture, Udaipur to evaluate the effect of Zn–Cu nano fertilizer on soil microbial population under maize (*Zea mays* L.) cultivation. The experiment comprised different treatments of Zn–Cu nano fertilizer arranged in a suitable experimental design with three replications. Soil microbial populations viz., bacteria (10^7 cfu g⁻¹ soil), fungi (10^5 cfu g⁻¹ soil) and actinomycetes (10^6 cfu g⁻¹ soil) were significantly influenced by Zn–Cu nano fertilizer treatments during both the years as well as pooled analysis. Among the treatments, T₁₀ [Zn–Cu nanofertilizer (0.20%)] recorded the highest bacterial population (52.35×10^7 cfu g⁻¹ soil), fungal population (10.30×10^5 cfu g⁻¹ soil) and actinomycetes population (17.92×10^6 cfu g⁻¹ soil) in pooled analysis, which were significantly superior over control. Application of Zn–Cu nanofertilizer (0.20%) increased bacterial, fungal and actinomycetes populations by 15.44, 14.06 and 13.78 per cent, respectively, over control in pooled analysis. The enhancement in microbial population might be attributed to improved nutrient availability, higher nutrient use efficiency and favourable soil biological conditions created by nano-sized micronutrients. In contrast, the control treatment recorded the lowest microbial population throughout the investigation. The findings of the study indicate that application of Zn–Cu nanofertilizer, particularly at 0.20 per cent concentration, can effectively improve soil microbial activity and soil biological health under maize cultivation, thereby contributing towards sustainable nutrient management and soil fertility maintenance.

Keywords: Nanourea, conventional urea, growth, LAI, yield and wheat

Introduction

Maize (*Zea mays* L.) is one of the major cereal crops of the world and ranks after wheat and rice in importance. Owing to its wide adaptability, the crop can be successfully cultivated under diverse agro-climatic conditions. Maize serves multiple purposes as it provides food and feed for humans and livestock, besides being utilized as a raw material in the manufacture of starch, oil, protein, sweeteners, alcoholic products and biofuel. In India, maize holds a significant position because of its extensive adaptability and cultivation across varied climatic regions. At present, the crop is grown over an area of 12.09 million hectares with a production of 43.41 million tonnes and an average productivity of 35.90 q ha⁻¹ (Govt. of India, 2024–25). In Rajasthan, maize occupies about 1.01 million hectares with an annual production of 2.68 million tonnes and an average productivity of 26.58 q ha⁻¹ (Govt. of India, 2024–25). The agro-climatic conditions of southern Rajasthan are highly favourable for maize cultivation, where the crop is predominantly grown during the kharif season under rainfed conditions. In recent years, maize productivity has improved considerably due to continuous genetic advancements, including the development of open-pollinated varieties, composites, double-cross and three-way hybrids, along with the introduction of superior single-cross hybrids that are widely preferred by farmers. Nano fertilizers have gained considerable attention in recent years as an innovative approach for improving nutrient management and sustaining crop productivity. These fertilizers supply nutrients in nano-sized particles, which enhance nutrient use efficiency because of their greater surface area and improved absorption by plants. Due to their controlled and targeted nutrient release, nano fertilizers reduce nutrient losses and lower the chances of toxicity caused by

excessive fertilizer application. Their efficient utilization also decreases the frequency and quantity of fertilizer application, thereby reducing input costs and improving economic returns to farmers (Sekhon, 2014) ^[1].

In addition to improving nutrient availability, nano fertilizers are considered environmentally safer alternatives to conventional fertilizers. Excessive use of traditional fertilizers often leads to nutrient leaching, soil degradation and environmental pollution, whereas nano fertilizers help maintain soil fertility and reduce adverse ecological impacts. Their application has been reported to enhance soil biological activity and support beneficial soil microorganisms, thereby contributing to improved soil health and sustainable agricultural production (Khan *et al.*, 2019) ^[2].

Among micronutrients, zinc and copper play important roles in various physiological and biochemical processes of plants as well as in regulating microbial activity in soil. Application of these nutrients in nano form may positively influence soil microbial populations by improving nutrient availability and creating favourable conditions for microbial growth and activity (Tripathi *et al.*, 2020) ^[3].

Therefore, understanding the influence of zinc-copper nano fertilizers on soil microbial population is important for developing sustainable nutrient management practices in maize cultivation. Keeping these aspects in view, the present investigation was undertaken to evaluate the effect of zinc-copper nano fertilizer on soil microbial population under maize cultivation.

Materials and Methods

The field experiment was conducted during the *kharif* seasons of 2023–24 and 2024–25 at the Instructional Farm of Rajasthan College of Agriculture, Udaipur, an area characterized by a semi-arid climate and sandy clay loam soils typical of the region. The study aimed to investigate how foliar application of Zn-Cu nanofertilizer influence soil microbial populations after maize harvest. The experiment was laid out in a randomized block design with three replications. The gross plot size was (6 m x 3.6 m = 21.6 m²). The experiment consisted of ten treatments viz., T₁- Control (only water), T₂- Bulk chitosan (0.01%), T₃ - ZnSO₄ (0.05%), T₄ - CuSO₄ (0.02%), T₅ - Zn-Cu nanofertilizer (0.01%), T₆- Zn-Cu nanofertilizer (0.04%), T₇-Zn-Cu nanofertilizer (0.08%), T₈- Zn-Cu nanofertilizer (0.12%), T₉ - Zn-Cu nanofertilizer (0.16%), T₁₀- Zn-Cu nanofertilizer (0.20%) was applied to maize var. PHM-3 (Pratap Hybrid Maize-3). In accordance with the recommended practices outlined in the Package of Practices by the Government of Rajasthan, the fertilizer application was carried out using the recommended dosage.

After the harvest of maize, soil samples were collected from each plot at a depth of 0–15 cm using a sterilized auger, ensuring representative sampling. The samples were processed immediately and analyzed for major microbial groups-bacteria, fungi and actinomycetes-using the serial dilution and plate count technique. Nutrient Agar, Rose Bengal Agar and Kenknight's Agar were used as selective media for bacteria, fungi and actinomycetes, respectively and colonies were incubated under controlled conditions before enumeration. The microbial populations were expressed as colony-forming units (cfu g⁻¹ soil). The statistical analysis of the obtained data was conducted using the analysis of variance (ANOVA) techniques, following the methodology. To compare the treatment means, the critical difference (CD) test was employed at a significance level of 5% (P=0.05). The critical difference test helps determine the minimum significant difference between treatment means that

indicates a statistically significant variation.

Results and Discussion

The results of the two-year investigation revealed a significant and consistent improvement in soil microbial population due to the application of Zn-Cu nano fertilizer treatments. All the microbial groups, namely bacteria, fungi and actinomycetes, responded positively to nano fertilizer application, though the magnitude of response varied among treatments. Among the different treatments, T₁₀ [Zn-Cu nanofertilizer (0.20%)] proved to be the most effective and recorded the highest microbial population in soil during both the years as well as pooled analysis. In pooled data, treatment T₁₀ registered bacterial, fungal and actinomycetes populations of 52.35×10^7 , 10.30×10^5 and 17.92×10^6 cfu g⁻¹ soil, respectively, which were markedly higher than those recorded under control (T₁). The increase in microbial population under T₁₀ was mainly attributed to the favourable influence of nano fertilizers on soil biological activity and nutrient availability, thereby creating a conducive environment for microbial growth and multiplication.

The increase in soil microbial population under Zn-Cu nano fertilizer treatments may be attributed to the greater availability of nutrients in soluble and readily utilizable forms, which stimulated microbial growth and activity in the soil. Nano fertilizers possess higher surface area and reactivity, resulting in improved nutrient use efficiency and gradual nutrient release, thereby creating favourable conditions for microbial proliferation. Enhanced nutrient availability under nano fertilizer application may have directly increased bacterial, fungal and actinomycetes populations in the rhizosphere (Kumar *et al.*, 2021) ^[6].

The improvement in microbial population may also be associated with enhanced root growth and release of root exudates under nano fertilizer application. Root exudates contain organic compounds, humic substances and enzymes that serve as important carbon and energy sources for soil microorganisms, thereby promoting microbial multiplication and activity. Humic substances released during nutrient transformation may further improve soil pH regulation, moisture retention, aeration and gas permeability, which collectively favour microbial growth and biological activity in soil. Increased microbial abundance under nano fertilizer treatments may consequently enhance nutrient mobilization, nutrient cycling and soil enzymatic activities (VandeVoort and Arai, 2019) ^[5].

The highest microbial population recorded under treatment T₁₀ [Zn-Cu nanofertilizer (0.20%)] indicates the beneficial role of balanced micronutrient supply in stimulating soil biological processes. Zinc acts as an important component of several microbial enzymes and metabolic pathways, whereas copper is involved in oxidation-reduction reactions and enzymatic activation. Adequate supply of these micronutrients in nano form possibly created a more favourable environment for microbial colonization and activity. Similar findings regarding enhancement of microbial population and soil biological activity following nano fertilizer application have also been reported by Raliya and Tarafdar (2013) ^[8], Rajput *et al.* (2018) ^[9], Nibin *et al.* (2019) ^[10], Meena *et al.* (2021) ^[11] and Tondy *et al.* (2021).

The lower microbial population observed under control treatment might be due to comparatively lower nutrient availability and less favourable conditions for microbial growth. Excessive and imbalanced use of conventional fertilizers may adversely affect soil biological activity, whereas nano fertilizers appear comparatively safer because of their controlled nutrient release and improved nutrient utilization efficiency. Enhanced

microbial activity in the rhizosphere under nano fertilizer application may also contribute to greater nutrient availability and improved nutrient uptake by plants. Overall, the present findings suggest that Zn–Cu nano fertilizer application can effectively improve soil microbial population and soil biological health under maize cultivation.

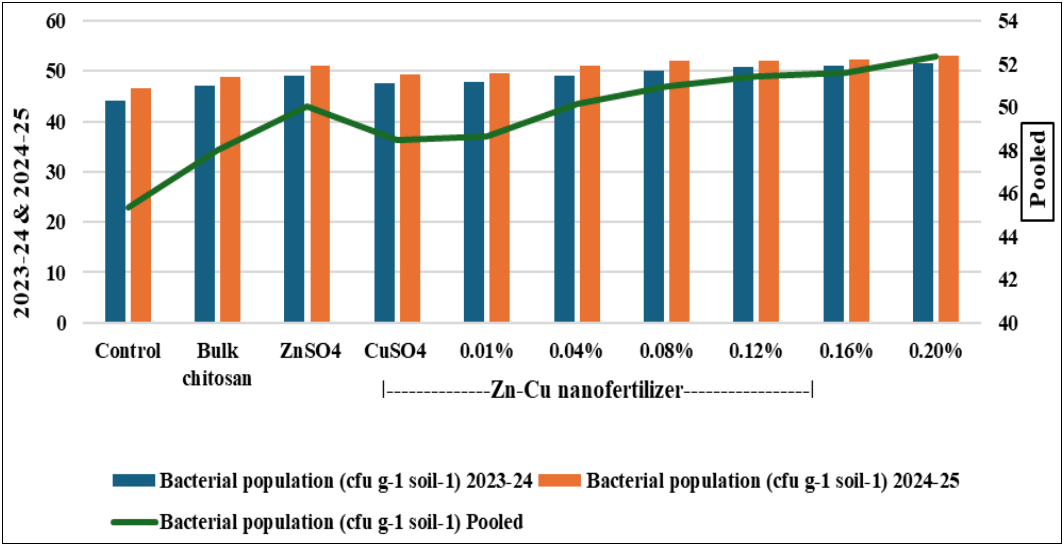


Fig 1: Effect of Zinc-Copper nanofertilizer on bacteria population of soil after harvesting of maize

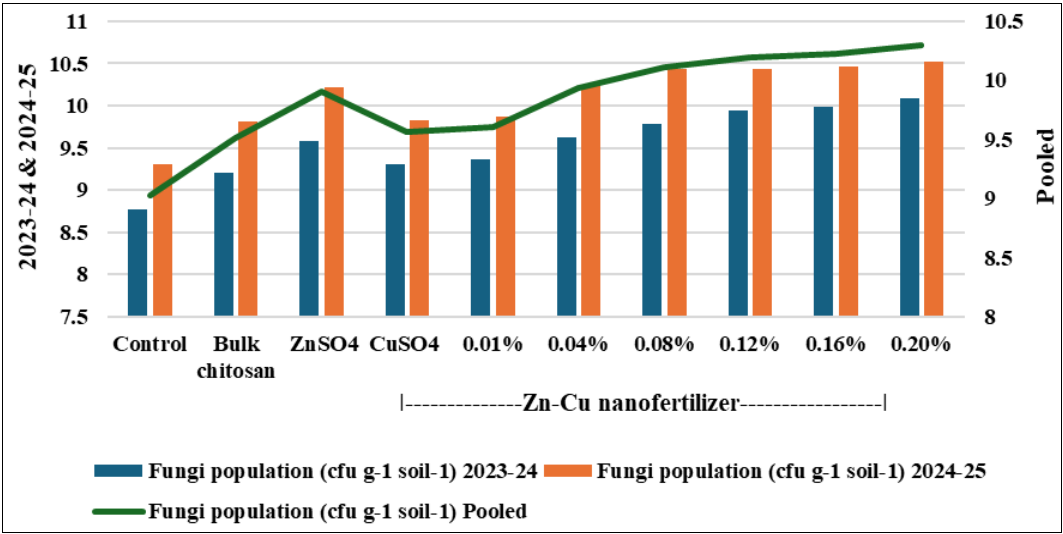


Fig 2: Effect of Zinc-Copper nanofertilizer on fungal population of soil after harvesting of maize

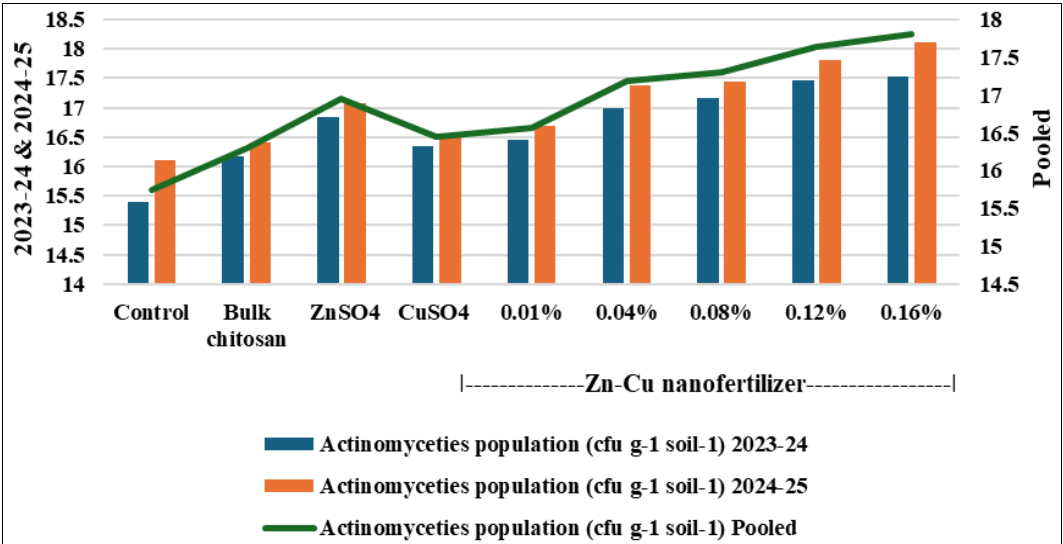


Fig 3: Effect of Zinc-Copper nanofertilizer on actinomycetes population of soil after harvesting of maize

Table 1: Effect of Zinc-Copper nanofertilizer on microbial population of soil after harvesting of maize

Treatments	Bacterial population ($\times 10^7$) (cfu g ⁻¹ soil)			Fungi population ($\times 10^5$) (cfu g ⁻¹ soil)			Actinomycetes population ($\times 10^6$) (cfu g ⁻¹ soil)		
	2023-24	2024-25	Pooled	2023-24	2024-25	Pooled	2023-24	2024-25	Pooled
T ₁	44.03	46.67	45.35	8.77	9.30	9.03	15.4	16.1	15.75
T ₂	47.06	48.89	47.98	9.21	9.81	9.51	16.17	16.41	16.29
T ₃	48.97	51.07	50.02	9.58	10.21	9.90	16.83	17.08	16.95
T ₄	47.58	49.35	48.46	9.30	9.82	9.56	16.34	16.56	16.45
T ₅	47.82	49.50	48.66	9.36	9.87	9.61	16.44	16.69	16.57
T ₆	49.16	51.08	50.12	9.62	10.25	9.94	16.99	17.38	17.19
T ₇	50.00	51.95	50.98	9.79	10.43	10.11	17.17	17.44	17.31
T ₈	50.82	52.05	51.43	9.94	10.44	10.19	17.47	17.81	17.64
T ₉	50.96	52.20	51.58	9.98	10.47	10.23	17.52	18.1	17.81
T ₁₀	51.56	53.15	52.35	10.09	10.52	10.30	17.71	18.12	17.92
SEm±	1.14	1.20	0.83	0.21	0.22	0.15	0.37	0.36	0.26
CD at 5%	3.38	3.56	2.37	0.62	0.65	0.43	1.08	1.07	0.74

Conclusion

The findings of the present investigation clearly revealed that the application of Zn–Cu nano fertilizer significantly influenced soil microbial population after harvest of maize. Among the different treatments, Zn–Cu nanofertilizer at 0.20 per cent concentration (T₁₀) proved to be the most effective in enhancing bacterial, fungal and actinomycetes populations during both the years as well as pooled analysis. The improvement in microbial abundance under nano fertilizer treatments may be attributed to enhanced nutrient availability, greater nutrient use efficiency and favourable conditions for microbial growth and activity in the soil environment.

The increased microbial population under Zn–Cu nano fertilizer application indicates improvement in soil biological health and microbial-mediated nutrient transformations. Adequate supply of zinc and copper in nano form possibly stimulated microbial metabolism, enzymatic activities and rhizospheric interactions, thereby promoting microbial proliferation in soil. In contrast, the control treatment recorded the lowest microbial population due to comparatively lower nutrient availability and less favourable conditions for microbial activity.

Overall, the study highlights the beneficial role of Zn–Cu nano fertilizer in improving soil microbial population under maize cultivation. Application of Zn–Cu nanofertilizer at 0.20 per cent concentration may therefore be considered a promising nutrient management strategy for maintaining soil biological health, improving nutrient cycling and supporting sustainable maize production systems.

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