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Effect of Nano Multi Micronutrients Formulation Nutrient Use Efficiency, Proximate Composition and Post- harvest Soil Fertility in Maize (*Zea mays* L.) Under Field Conditions

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ABSTRACT

The field experiment was carried out during the winter seasons of 2023 and 2024 at the experimental field of Rashtriya Chemicals and Fertilizers Limited, Chembur, Mumbai, Maharashtra, India to study the impact of nano multi micronutrient (NM) on maize growth. The experiment was designed with Randomized Block Design with 12 treatments, containing control (only water), Recommended Dose of Fertilizer (RDF), various concentrations of NM formulation having copper (Cu), zinc (Zn), manganese (Mn), iron (Fe) and boron (B) from 20 to 0.156 mg applied per one square meter plot, commercial micronutrients and micronutrient salts. Results showed that 100% RDF+5 mg NM (T5), 0.312 mg NM (T_9), and 0.156 mg NM (T_{10}) NM applied via drenching yielded better nutrient uptake (NU), apparent recovery (ANR), and agronomic efficiency (AE). The NU (kg ha^{-1}) of phosphorus (P) (314.612), potassium (K) (372.192), Cu (0.174), Fe (7.12), Mn (0.488), and Zn (1.373) were higher in treatment T_5 (5 mg NM). The ANR was 42471.68% higher in treatment T_{10} and 111.49% higher in treatment T_5 for nitrogen (N), P, and K compared to 100% RDF. The protein and chlorophyll content were high in treatment T_9 of NM. Proximate analysis indicated improved quality and nutrient content in treatments T_5 and T_9. Treatments T_5, T_9, and T_{10} were most effective in enhancing NU, ANR, AE, proximate and chlorophyll content. Soil fertility was higher in NM treated soils. Lower concentrations of the NM formulation appear to be more effective in all traits.

KEYWORDS: Nano multi micronutrient, maize, nutrient use efficiency, proximate analysis

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1. INTRODUCTION

Maize (*Zea mays* L.) is an important cereal crop and has high health as well as nutritional value (Shah et al., 2016, and Bhaumik et al., 2025). Due to its nutritional quality and traditional importance as a food, it has high demand throughout the world (Serna Saldivar and Perez- Carrillo, 2016). The modern maize improvement has rapidly enhanced the productivity, supporting food, feed, and industrial demand. Systematic breeding and coordinated research programs in India help to develop maize seeds of high-yielding hybrids, stress tolerance and quality protein (Yadav et al., 2014). Higher losses of the conventional fertilizers due to leaching, runoff, soil fixation and volatilization resulted in low productivity (Bhatt et al., 2025, and Zhang et al., 2015). In nutrient-deficient soils, micronutrient fertilizers like Cu, Zn, Mn, Fe, and B increased the crop sustainability and productivity (Dawar et al., 2025, Yadav et al., 2025). Integrated management system improved maize productivity by application of Cu, Zn, Mn, Fe, and B when combined with N, P, and K (Samiksha et al., 2024). Micronutrients act as a cofactor for the enzymes, which increased the chlorophyll content in maize (Jerecki et al., 2025 and Ssemugenze et al., 2025). Application of nano Zn and nano Fe increased the nutrient use efficiency and boosted the productivity (Sary et al., 2025). Nano Fe increased the productivity in droughts and saline soils. It acts as a bio-stimulant, thus increasing NU and chlorophyll (Alsamadany et al., 2024). Under the calcareous soil, stress conditions, and drought tolerance, nano Mn, nano Zn and nano Cu particles enhanced overall crop productivity (Karthivelan et al., 2025, and Wang et al., 2022). Nano B boosted the crop productivity in maize as compared to conventional fertilizers (Nouraein, 2019 and Jasim et al., 2025). Application of nano Zn and nano Fe boosted the nutrient use efficiency, NU by reducing the conventional fertilizers concentrations by 25 to 50% (El- Habbak et al., 2019). The NU in N, P and K was registered high in 75% N through urea and 25% N through two foliar sprays of nano urea (Bhukya et al., 2024). Application of nano Zn and nano Mn enhanced the apparent recovery as compared to conventional fertilizers in nutrient-deficient soils (Sary and El-Aziz, 2025). Nano Zn and nano Mn improved maize productivity, nutrient use and AE under drought stress conditions (Vaisnavi et al., 2025). The protein content and protein yield were enhanced by the application of nano Zn, nano Fe and nano urea when compared to the conventional fertilizers (Kumar et al., 2024). Recent studies indicated that the application of single and combined micronutrients with N, P and K improves overall productivity in maize but combined applications showed a synergetic increase in quality of crop (Samiksha et al., 2024). Foliar application of nano Zn and nano Cu increased the soil microbial population and physical properties of the soil, thus maintained the soil fertility (Khardia et al., 2022). The increased protein and starch accumulation in maize was due to the application of nano Zn and nano Fe. It also increased the nutritional quality of maize through proximate analysis (Abbas et al., 2024). Field trial in maize was basically a bridge between the laboratory research and commercial adoption to evaluate the performance in real-world agricultural fields (Insights editor, 2025). Hence, this study aimed to assess and compare the total NU, ANR, ARE, soil fertility, proximate analysis and chlorophyll content in the field trial of maize by using NM formulation (Cu, Zn, Mn, Fe, B), alongside commercial and salts of micronutrients.

2. MATERIALS AND METHODS

2.1. Environmental conditions

The field trial experiment was performed with red soil in two winter seasons of 2023 and 2024. It was carried out at a Research and Development Centre of Rashtriya Chemicals and Fertilizers Limited, located at Chembur, Mumbai, Maharashtra (19.034434° N latitude and 72.890891° E longitude). The study comprised of 12 treatments performed in triplicate. Surface soil sample (0–15 cm) was collected and analyzed prior to sowing for N, P, K and micronutrients. The experimental soil was slightly acidic with pH of 5.51, electrical conductivity of 0.21 ms and available N, P and K contents of 178.2, 59.87 and 356.35 kg ha^{-1} respectively. During the trial periods of both the seasons the average relative humidity was 75 and 75.25% and the temperature recorded was 26.5°C for both the seasons. The average rainfall during both the seasons was 500 and 700 mm.

2.2. Experiments and treatments

A NM formulation containing Zn, Fe, Mn, Fe, Cu and Zn was synthesized in a laboratory using the physical ball milling technique. The synthesized particles were further characterized for its particle size distribution, zeta potential, X-ray diffraction (XRD), Infra-red Spectroscopy (IR), Field Emission–Scanning Electron Microscopy (FE-SEM) and Transmission Electron Microscopy (TEM). It was performed to successful confirmation of nano particles. After achieving the nano size particles, a field experiment was conducted. The plot size of each plot was one square meter in area and was replicated thrice in triplicate. The different concentrations of nano micronutrients were dissolved in one litre of water. The maize seeds were directly sown in soil 30 cm apart from each other. All the treatments received 100% RDF and various doses of nano micronutrients were added to the soil through drenching. The experiment was laid out in a Randomized Block Design with 12 treatments. T_1 Absolute control (only water), T_2 100% RDF in ratios of 120:60:40

NPK, T_3 100% RDF+20 mg plot^{-1} nano micronutrient, T_4 100% RDF+10 mg plot^{-1} nano micronutrient, T_5 100% RDF+5 mg plot^{-1} nano micronutrient, T_6 100% RDF+2.5 mg plot^{-1} nano micronutrient, T_7 100% RDF+1.25 mg plot^{-1} nano micronutrient, T_8 100% RDF+0.625 mg plot^{-1} nano micronutrient, T_9 100% RDF+0.312 mg plot^{-1} nano micronutrient, T_{10} 100% RDF+0.156 mg plot^{-1} nano micronutrient, T_{11} 100% RDF+commercial micronutrient, T_{12} 100% RDF+micronutrient salts. The commercial micronutrient was applied as a 0.25% foliar spray while micronutrients salts at 25 kg ha^{-1} concentration through drenching.

2.3. *Cultural operations*

The corn seeds of hybrid variety F_1 sweet corn, sweet 16, were sown in each plot and placed 30 cm apart at the depth of 3–4 cm. The seeds were sown for germination into the sprouts. After germination, the fertilizer was applied at 20 days as per treatment schedule. Weeding was done simultaneously as and when required. At physiological maturity, the crop was harvested after 100 days. The earthing of the soil was done twice at 30 and 60 days.

2.4. *Observation recorded*

Each treatment grain and stover samples were collected, dried in sun, finely ground and subjected to acid digestion for the estimation of nutrient concentration. The digested samples were analyzed using Inductively Coupled Plasma (ICP) spectrometer. The nutrient uptake, apparent recovery and agronomic efficiency were calculated. Nitrogen concentration was estimated using the Kjaldahl method which involves digestion, distillation, and titration on a Kjeldahl apparatus. Based on nitrogen concentration protein content and protein yield was calculated. Leaf chlorophyll content was determined by extracting the pigments from fresh leaf tissues in 80% acetone. It was further centrifuged and absorbance was measured using a spectrophotometer.

In proximate analysis the parameters like moisture, crude protein, crude fiber, crude fat, total ash and acid insoluble ash were determined by test methods (Anonymous, 1975). Neutral detergent fiber (NDF) and acid detergent fiber (ADF) were estimated by (Anonymous, 1975).

2.5. *Analytical procedures*

The soil samples were well mixed to ensure uniformity, allowed to air dry, and then sieved through a 2 mm sieve. In the soil analysis, the Kjeldahl on Pelikan Kelplus-Classic DX instrument was used to estimate the N content; the Thermo Scientific Evolution 201 instrument was used to estimate the P; the Systronic brand flame photometer, pH meter, and conductivity meter were used to estimate the potassium, pH, and conductivity; and the Thermo Scientific iCAP 6000 series instrument was used to estimate the micronutrients using an inductively coupled plasma membrane. The Thermo Scientific Evolution 201 and Thermo Scientific ultracentrifuge and spectrophotometer were used to estimate the chlorophyll.

2.6. *Statistical analysis*

Data for all the parameters were pooled across both seasons and subjected to statistical analysis using analysis of variance (ANOVA). The treatment effects were tested at 5% level of significance using the critical difference (CD) test. The standard error of the mean (SEm±) and corresponding CD values were presented in the tables to compare among various treatments. Based on the statistically analyzed data, appropriate equations were applied to compute experimental parameters.

- Protein yield (kg ha^{-1})=Protein content (%)×seed yield kg ha^{-1}/100
- Protein content (%)=Grain protein content (%)×6.25
- ANR (%)=Nutrient uptake in fertilized plot (kg ha^{-1})-Nutrient uptake in control plot (kg ha^{-1})×100/ Nutrient applied (kg ha^{-1})
- AE (kg ha^{-1})=Yield in fertilized plot (q ha^{-1})-Yield in control (q ha^{-1})/Nutrient applied (kg ha^{-1})
- Total chlorophyll content mg g^{-1} FW=(20.2 × A_{645}+8.02 × A_{663}) ×V/1000×W

3. RESULTS AND DISCUSSION

3.1. *Yield*

The grain and stover yield with the nano micronutrient treatment along with RDF was graphically depicted in Figure 1 and Figure 2. The highest grain yield of 149.03 qha^{-1} was recorded in treatment T_9, which was significantly higher than control, commercial and salts of micronutrients.

The maximum stover yield was observed in treatment T_9 of 53.03 q ha^{-1} which was significantly higher than RDF alone

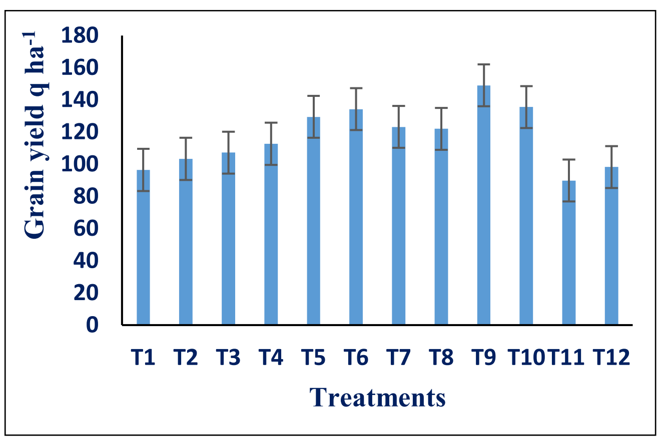

Figure 1: Grain yield (SEm±13.05, CD (p=0.05) 40.6

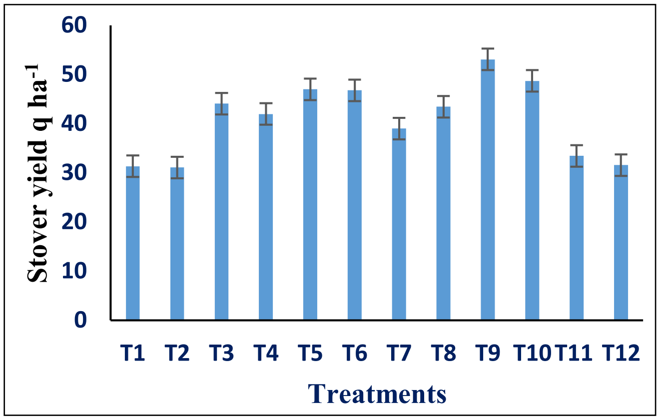

Figure 2: Stover yield (SEm±1.80, CD (p=0.05) 5.61

and control. This indicates that the nano micronutrient formulation application improved the efficiency of grain and stover yield. These findings were similar to the results in which application of nano N and nano Zn in combination with conventional fertilizers tends to increase the crop yields and nutrient uptake (Gopinath et al., 2025). Similar observations were also found in research of applying of nano Zn and nano N with the reduced dose of conventional fertilizers increases the yields in maize by 66.2 to 68.2%. The yield was also maximum in treatment with nano Zn, nano N and 100% Recommended rate of Nitrogen of 6.55 and 6.43 t ha^{-1} compared to only phosphorus and potassium of 3.35 3.24 t ha^{-1} (Upadhyay et al., 2023).

3.2. Nutrient uptake

The nutrient uptake was the total quantity of the nutrient absorbed by the plant from soil and accumulated in different plant parts during its growth period. The nutrient management practices on total nutrient uptake by application of NM formulation were presented in Table 1, which shows that treatment T_5 consistently outperforms other treatments in nearly all measured nutrient categories. Among the treatments, the application of RDF integrated with NM formulation showed remarkable improvement of the nutrient uptake in both macro and micro nutrients when compared with T_1, T_2, T_{11}, and T_{12}. Treatment T_5 recorded the highest uptake of P (314.612 kg ha^{-1}), K (372.192 kg ha^{-1}), Cu (0.174 kg ha^{-1}), Fe (7.12 kg ha^{-1}), Mn (0.488 kg ha^{-1}) and Zn (1.373 kg ha^{-1}) indicated maximum nutrient utilization and uptake. The N uptake of 86.672 kg ha^{-1} was higher in treatment T_9. The observed differences among the treatments were statistically significant as indicated by CD at p=0.05% values. The results confirmed that the treatments T_5, T_9, and T_{10} provided significantly higher NU compared to all other treatments, making it the most nutrient efficient treatment across the board. These findings aligned with the research conducted by El- Saadony et al.

Table 1: Effect of nutrient management practices on total nutrient uptake at harvesting

Treatment	N kg ha^{-1}	P kg ha^{-1}	K kg ha^{-1}	B kg ha^{-1}	Cu kg ha^{-1}	Fe kg ha^{-1}	Mn kg ha^{-1}	Zn kg ha^{-1}
T_1	29.509	108.528	174.402	0.299	0.077	1.748	0.156	0.670
T_2	40.693	153.098	186.033	0.322	0.136	3.062	0.233	0.688
T_3	52.601	153.205	206.675	0.295	0.115	1.34	0.224	0.726
T_4	55.767	180.788	217.277	0.464	0.149	5.458	0.284	0.836
T_5	62.38	314.612	372.192	0.541	0.174	7.12	0.488	1.373
T_6	62.385	172.432	242.355	0.495	0.107	1.794	0.231	0.936
T_7	40.727	183.705	212.62	0.336	0.093	5.134	0.282	1.021
T_8	57.835	187.68	218.873	0.441	0.109	6.532	0.29	0.981
T_9	86.672	234.02	312.828	0.67	0.154	4.85	0.365	1.077
T_{10}	76.462	197.815	271.633	0.76	0.136	3.853	0.306	0.925
T_{11}	36.645	137.718	191.143	0.254	0.081	3.33	0.232	0.609
T_{12}	34.421	127.637	186.598	0.292	0.078	1.632	0.221	0.607
SEm±	4.772	22.725	16.742	0.055	0.007	0.414	0.018	0.055
CD p= 0.05%	10.504	50.017	36.848	0.121	0.015	0.911	0.04	0.121

T_1: Absolute control (only water); T_2: 100% RDF in ratios of 120:60:40 NPK; T_3: 100% RDF+20 mg plot^{-1} nano micronutrient; T_4: 100% RDF+10 mg plot^{-1} nano micronutrient; T_5: 100% RDF+5 mg plot^{-1} nano micronutrient; T_6: 100% RDF+2.5 mg plot^{-1} nano micronutrient; T_7: 100% RDF+1.25 mg plot^{-1} nano micronutrient; T_8: 100% RDF+0.625 mg plot^{-1} nano micronutrient; T_9: 100% RDF+0.312 mg plot^{-1} nano micronutrient; T_{10}: 100% RDF+0.156 mg plot^{-1} nano micronutrient; T_{11}: 100% RDF+commercial micronutrient; T_{12}: 100% RDF+micronutrient salts

(2021), which highlighted that the nano micronutrients of lower concentration (50 mg l^{-1}) had higher nutrient uptake than higher concentrations of 500 mg l^{-1}. These results were in agreement with those reported by Hasan et al. (2021) and El- Saadony et al. (2021), in which the higher doses of nano micronutrients can be phytotoxic, resulting in poor nutrient uptake by blocking the roots of plants.

3.3. Post-harvest soil analysis

Post-harvest soil analysis was performed to estimate changes in soil physicochemical properties and nutrient status of the soil. The post- harvest soil analysis at the plant harvest to see the changes in soil properties through NM application was depicted in Table 2, which indicated that pH and conductivity were in the normal favorable range over all the treatments. Among the treatments, T_9 recorded the highest N and K (314.88 and 384.703 kg ha^{-1}). The treatment T_5 showed higher available P (71.515 kg ha^{-1}) along with higher micronutrient availability. The micronutrient content in B, Cu, Fe, Mn and Zn was 0.247, 4.288, 30.192, 88.751 and 3.279 ppm respectively. The application of RDF integrated with NM formulation improved the nutrient status of soil compared to T_1, T_2, T_{11} and T_{12} treatments. The lower concentrations of treatments T_4, T_5, T_9 and T_{10} elevated the nutrient concentration in post-harvest soil analysis, enhancing the soil fertility. These findings aligned with the research conducted by Mirbakhsh, 2023, in which soil fertility was increased at post-harvest soil analysis due to high surface area and reactivity of nano fertilizers. The combination of zinc and zinc sulphate integrated with inorganic fertilizers boosted soil fertility and nutrient uptake thereby giving rise to productivity and sustainable agriculture (Verma et al., 2024).

3.3. Apparent recovery (ANR)

ANR was the measure of how much fertilizer applied was taken up by the crop. The ANR (%) of NM formulation (B, Cu, Mn, Zn, B) over the standard fertilizer treatment T_2 (100% RDF) for various treatments was graphically depicted in Figure 3. This showed how efficiently each treatment enhanced the nano micronutrient uptake compared to RDF alone. T_{10} reflected higher recovery across all treatments,

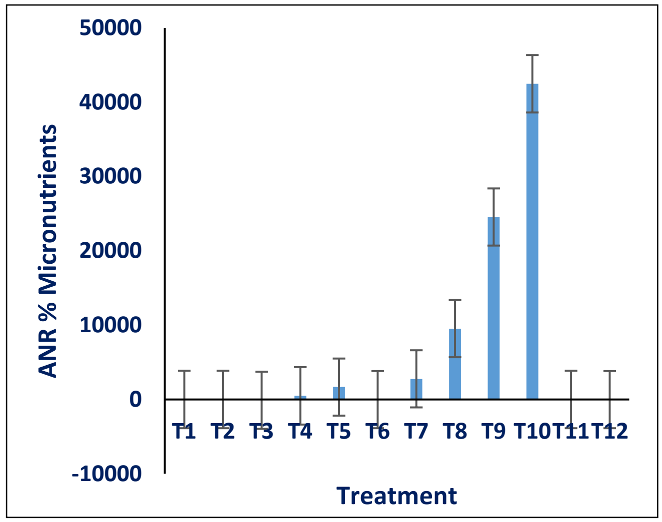

Figure 3: Effect of nutrient management practices on ANR of applied nano micronutrients

Table 2: Effect of nutrient management practices on soil fertility after harvest

Treatment	pH	EC ms	N kg ha^{-1}	P kg ha^{-1}	K kg ha^{-1}	B ppm	Cu ppm	Fe ppm	Mn ppm	Zn ppm
T_1	5.98	1.245	152.1	46.5	310.5	0.198	1.513	18.0	26.7	1.079
T_2	6.208	1.303	224.3	65.6	365.7	0.209	2.678	27.8	67.1	1.073
T_3	6.33	1.138	240.5	69.9	351.8	0.212	2.548	30.1	65.5	2.333
T_4	6.388	1.125	256.2	68.2	357.2	0.239	3.013	27.9	69.0	3.043
T_5	6.153	1.167	220.0	71.5	375.3	0.247	4.288	30.1	88.7	3.279
T_6	5.954	1.808	167.7	51.3	350.3	0.181	2.098	20.7	35.1	1.315
T_7	5.883	1.402	193.6	51.4	335.9	0.23	2.812	24.3	68.2	2.243
T_8	8.816	1.2	195.0	57.8	366.3	0.413	2.282	19.0	27.6	1.48
T_9	6.351	1.258	314.8	70.3	384.7	0.222	3.267	29.0	37.5	2.012
T_{10}	6.578	1.25	268.4	68.5	361.5	0.248	2.395	27.9	34.9	2.443
T_{11}	5.939	1.388	189.2	61.8	326.6	0.377	1.648	18.8	29.2	1.658
T_{12}	5.865	1.313	158.5	54.1	321.4	0.22	1.59	19.4	27.9	1.513
SEm±	0.17	0.28	68.70	3.18	47.8	0.093	0.841	4.36	20.3	0.858
CD *p*= 0.05%	0.38	0.63	151.2	7.00	105.2	0.204	1.85	9.60	44.8	1.889

42471.68%. treatment T_9 also performed exceptionally well, 24548.12%. T_{11} and T_{12} exhibited low apparent recoveries across all the treatments. As the concentration of NM decreased, ANR generally increased, peaking at T_9 and T_{10}. These results were consistent with the findings of Kumar et al. (2023), where the ANR was high in treatment with RDF integrated with nano N (4 ml l^{-1}), nano Zn (0.3 g l^{-1}). It was largely due to the increased surface area of nano fertilizers, which boosted recoveries and nutrient uptakes.

ANR (%) indicated how efficiently the plants utilized the nutrients from each treatment, relative to T_2 (100% RDF). The effect of nutrient management practices on the ANR of applied NPK is graphically depicted in Figure 4. Treatment T_5 attained the highest ANR (111.493 %), indicating the most efficient nutrient uptake. Treatment T_9 and T_{10} (66.75 and 47.07%) also had high recoveries, suggesting the beneficial effects of lower nano micronutrient concentrations. Treatment T_{11} and T_{12} showed negative recovery, implying a potential reduction in NU or loss. These results were in agreement with those reported by Asha Kiran et al. (2024) and Hasan et al. (2021), in which the application of nano-diammonium phosphate and nano urea enhances the apparent recoveries along with micronutrients like Zn and Fe. Due to this, the NU of N, P, and K was increased.

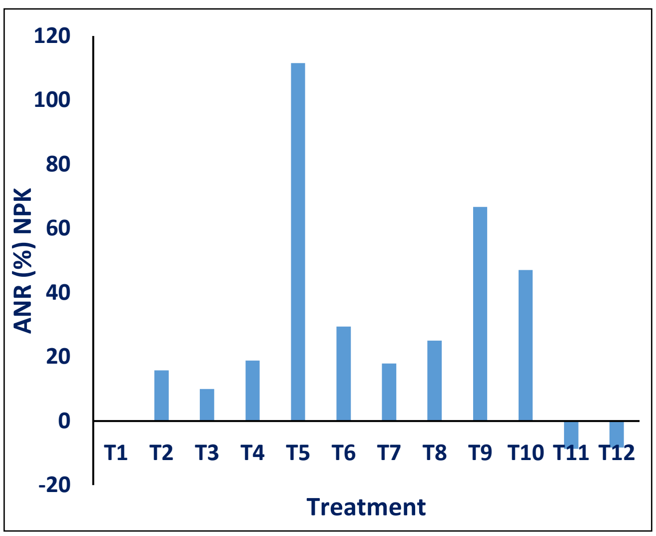

Figure 4: Effect of nutrient management practices on ANR of applied NPK

3.4. *Agronomic efficiency (AE)*

Agronomic efficiency was the increase in economic yield of a crop obtained per unit of the fertilizer applied. The AE (kg kg^{-1}) of the NM formulation containing Zn, Cu, Mn, Fe and B is graphically depicted in Figure 5. The agronomic efficiency was found to be high in treatment T_{10} of 499025 kg kg^{-1} of the nutrient applied. Treatment T_8 and T_9 also achieved extremely high AE of 110169.13 and 277490.48

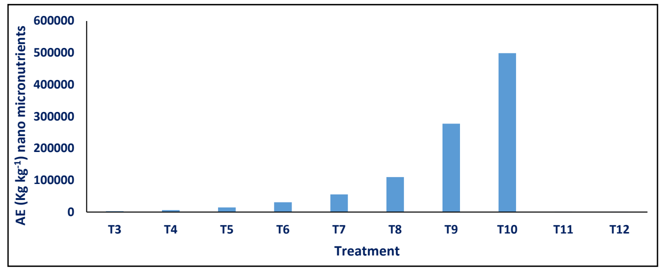

Figure 5: Effect of nutrient management practices on AE (kg kg^{-1}) of applied nano micronutrients

kg $kg^{-1,}$ respectively. As the NM doses decreased, there was a significant rise in AE, which enhanced nutrient use efficiency at lower concentrations. Treatment T_{11} and T_{12} (commercial and salts of micronutrients) depicted very low AE as compared to NM. These findings were similar to the results of Sary and Abd El-Aziz 2025, supporting the observation that the lower concentrations of nano fertilizers like nano Zn, nano Mn and nano Fe at a concentration of 100 ppm elevated the NU and agronomic efficiencies.

3.5. *Proximate analysis*

Proximate analysis was the quantitative estimation of nutritional components present in plants. It was commonly used to determine the nutritional quality of fodder and grain samples. The effect of nutrient management practices on proximate analysis with the application of NM was presented in Table 3. The results indicated considerable variations in moisture, crude protein, crude fiber, crude fat, ash content, Neutral Detergent Fiber (NDF) and Acid Detergent Fiber (ADF). Treatment T_6 recorded the highest crude protein content (6.86%). Treatment T_5 showed higher crude fiber content and NDF (27.15, 70.77%), respectively. Treatment T_2 revealed ADF content of 40.1285%. Crude fat was high in treatment T_3 (1.305%) while T_{10} exhibited high total ash content of 10.9%. The treatments with the NM formulation exhibited better NDF and ADF and protein content when compared to Control T_2, commercial micronutrients T_{11} and salts of micronutrients T_{12}. It indicated the improvement of nutritional quality of the maize biomass. These results were consistent with the findings of Purnima et al., 2025, in which the nano Zn (10 ppm) and nano urea (1%) concentration enhanced the nutritional quality of maize increasing crude protein content to 9.7%.

3.6. *Grain protein content, protein yield and chlorophyll content*

The grain protein content expressed the total amount of the protein present in maize grain whereas grain protein yield is the total quantity of the protein produced per unit area by multiplying grain protein content with grain yield (Mosse, 1990). The effect of NM formulation on protein content, protein yield and chlorophyll content was shown in Table 4. The treatment T_9 attained the highest protein content at

Table 3: Effect of nutrient management practices on proximate analysis of maize

Treatment	Moisture (%)	Crude protein (%)	Crude fiber (%)	Crude fat (%)	Total ash (%)	Acid insoluble ash (%)	NDF (%)	ADF (%)
T_1	7.085	6.54	26.855	1.135	8.37	1.29	70.215	38.92
T_2	8.83	6.675	25.355	1.1	8.085	1.41	69.135	40.125
T_3	8.415	5.64	28.13	1.305	9.105	1.395	70.3	39.76
T_4	3.76	6.495	25.025	1.185	8.325	1.205	68.875	37.795
T_5	7.265	6.365	27.155	1.105	8.29	1.53	70.775	38.45
T_6	7.035	6.86	26.265	0.975	9.08	1.735	68.765	38.72
T_7	4.29	4.39	24.77	1.115	8.285	1.73	67.935	38.935
T_8	6.595	6.8	26.465	0.90	9.105	1.695	69.035	39.6
T_9	4	6.16	25.575	0.93	7.72	1.36	68.7	39.165
T_{10}	4.905	5.9	27.285	0.89	10.9	1.415	67.785	37.64
T_{11}	5.295	6.305	28.895	1.23	8.45	1.39	68.89	37.205
T_{12}	3.1	5.95	27.63	0.705	6.24	1.895	65.84	37.44

Table 4: Effect of nutrient management practices on protein content, protein yield and chlorophyll

Treatment	Protein content (%)	Protein yield (kg ha^{-1})	Chlorophyll
T_1	1.08	104.16	2.106
T_2	1.4	144.65	2.4
T_3	1.5	160.87	2.43
T_4	1.72	193.84	2.81
T_5	1.6	207.17	2.874
T_6	1.69	226.91	2.084
T_7	0.9	110.85	2.458
T_8	1.61	196.42	2.477
T_9	2.02	301.04	2.893
T_{10}	1.97	267.03	2.665
T_{11}	1.55	139.31	2.563
T_{12}	1.37	134.63	2.236

2.02% followed by T_{10} at 1.97%. The lowest protein content was observed in treatment T_1 at 1.08%. The grain protein yield was higher in treatment T_9 301.04 kg ha^{-1}, followed by 267.03 kg ha^{-1} in treatment T_{10}. Treatment T_1 showed lowest protein yield of 104.16 kg ha^{-1} among the various treatments. This significant difference indicated that treatment T_9 and T_{10} resulted in higher protein content and protein yield. These findings aligned with the research conducted by El-Khouly, 2025, in which the application of nano Zn and nano Mn significantly increased the protein content when compared with the chelates of Zn and Mn.

The chlorophyll content was determined by Arnon's 1949 method, in which treatment T_9 had the highest chlorophyll content of 2.893 followed by treatment T_5 of 2.874, when compared with T_1, T_2, T_{11} and T_{12} of 2.106, 2.4, 2.563 and 2.236 respectively. These findings were similar to the research conducted by Ahmed et al., 2024, where the nano Zn of 2 g l^{-1} concentration significantly increased the chlorophyll content under the stress conditions. It boosted the metabolic activities in plant cells.

4. CONCLUSION

The drenching application of 100% RDF integrated with lower doses of NM formulation (5, 2.5, 1.25, 0.625, 0.312 and 0.156 mg) was found to be more effective in increasing NU, ANR, AE, protein content and yield, chlorophyll, proximate analysis and post- harvest soil fertility. The nutritional quality of the maize fodder increased with the NM formulation along with RDF. Thus, the lower doses of NM were more favorable and economical in maize crop.

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