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Effect of integrated application of nano urea and conventional urea on soil parameters, nutrient uptake and nitrogen use efficiency of winter maize (*Zea mays* L.)

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ABSTRACT

Among agricultural inputs, nitrogenous fertilizers are critical for food security, yet their low nitrogen use efficiency (30–50%) imposes both environmental and economic costs. Nano urea offers a promising alternative, provided its dose is optimized to realize its full benefit. To determine this optimal dose, a field experiment was conducted during rabi 2025–26 at Dr. Rajendra Prasad Central Agricultural University, Bihar, India, comprising eight treatments: an unfertilized control, 100% RDN through urea alone, and 100%, 85%, and 70% RDN combined with foliar nano urea at 2.5 ml/l or 1.25 ml/l, applied at the V3 (three-leaf) and tasseling stages. Result showed that 100% urea with two foliar sprays of nano urea (2.5 ml/l) performed best, increasing nutrient uptake by 12.28% over urea alone, whereas 85% urea with 2.5 ml/l nano urea showed only 018% reduction in nutrient uptake but all are statically at par with 100% Urea. Additionally Agronomic efficiency, physiologically efficiency, Apparent recovery efficiency, Nutrient harvest index highest for 100% urea with two foliar sprays of nano urea (2.5 ml/l), 100% Urea, 70% urea with two foliar sprays of nano urea (2.5 ml/l) highest in all the cases but statically non-significant with 85% urea with two foliar sprays of nano urea (2.5 ml/l). However, post-harvest soil parameters did not show did not differ significantly among treatments. Principal component analysis (explaining 89.9% of total variance) clustered the 100%- and 85%-urea nano-urea treatments together with urea alone on the positive axis, distinctly separating them from the unfertilized control, and grain yield showed strong positive correlations with SPAD reading, nitrogen uptake, and agronomic efficiency ($r > 0.80$). These findings collectively support nano urea as a viable strategy for improving nitrogen use efficiency while reducing dependence on conventional urea.

Keywords: Nano fertilizers, Nutrient use efficiency, Winter maize, Grain yield, Agronomic efficiency, Nutrient uptake, Nutrient use efficiency

Introduction

Maize (*Zea mays* L.) is a key crop in Bihar, cultivated across roughly 5.58 lakh hectares with an average yield of 7,262 kg/ha (UPAg, 2023–24) above the national average of 5,529 kg/ha, yet still short of the attainable potential of 8.5 t/ha (Jat *et al.*, 2025) [1]. As a nutrient-demanding crop (Setiyono *et al.*, 2010) [2], maize relies heavily on efficient nitrogen management for higher yields. Nitrogen, a core component of proteins, chlorophyll, enzymes, and growth hormones, drives cell division, cell enlargement, and photosynthesis, making its adequate supply essential for healthy growth and productivity (Leghari *et al.*, 2016) [3].

Urea remains the dominant nitrogenous fertilizer, yet its nitrogen use efficiency is poor (30–50%), resulting in substantial nitrogen loss to the environment (Govindasamy *et al.*, 2023) [4]. This inefficiency also carries a heavy economic cost; the government spends nearly ₹1.32 lakh crore annually on nitrogenous fertilizer subsidies, out of a total ₹1.95 lakh crore fertilizer subsidy outlay (Department of Fertilizers, 2023–24) [5]. Additionally, the sudden influx of readily available nitrogen from urea stimulates microbial activity that consumes soil organic carbon, accelerating its depletion (Chen *et al.*, 2014) [6]; a serious concern given the already low organic carbon reserves in Indian soils. These issues underscore the need to improve nitrogen use efficiency and reduce dependence on conventional urea through alternatives like nano urea.

Owing to their extremely small size (1–100 nm), nanoparticles carry a high nutrient load and are absorbed more readily by plants than conventional fertilizers. Applied as a foliar spray, they penetrate the leaf cuticle and stomata (10–80 µm) directly and may also enter cells via endocytosis, unlike conventional fertilizers, which rely on slower diffusion and active transport. This improves nutrient solubility, delivery, and overall nitrogen use efficiency (Nongbet *et al.*, 2022) [7].

While 4% nano urea has been reported to replace about 25% of conventional urea, findings vary across studies. This study uses a higher-concentration 12% nano urea to test whether it can achieve a greater substitution while improving maize yield. Accordingly, a field experiment titled "Effect of Integrated Application of Nano Urea and Conventional Urea on Soil parameters, Nutrient uptake and Nitrogen Use Efficiency, and

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Economics of Winter Maize (*Zea mays* L.)" was conducted on problem soils of Samastipur district, Bihar, during Rabi 2025–26, with the objective of evaluating the effect of 12% nano urea on the nitrogen use efficiency of winter maize.

Materials and method

Experimental site

An experiment conducted at Pusa farm of Dr. Rajendra Prasad Central Agricultural University, India to understand performance of combined application of nano urea and nitrogenous fertilizer on yield and nitro-

gen use efficiency of winter maize. The experimental area located at 25.9780° N latitude and 85.6488° E longitude, with an altitude of 52.9 meters above mean sea level (MSL). The crop growing period (Standard meteorological week of 46 in 2025 to 18 in 2026) in experimental area has characterized by highest temperature of 35.37° Celsius and lowest temperature 5.21° Celsius, average relative humidity of (%) (58-107) and highest rainfall of 29 mm. The experimental site's soil characterized as sandy loam soil and has pH, E.C (dS/m), soil organic carbon of (%) of 8.29, 0.34, 0.42 respectively & available nitrogen (kg/ha), available phosphorus (kg/ha), available potassium (kg/ha) of 187, 11.78, 111.29 respectively.

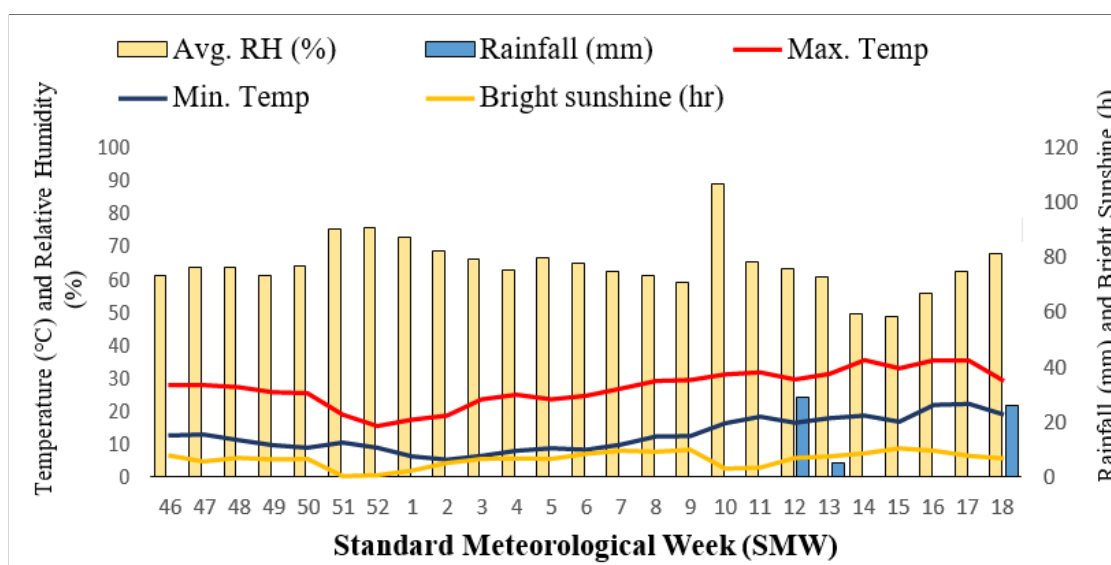


Figure 2.1. Weekly meteorological data (maximum and minimum temperature, average relative humidity, rainfall, and bright sunshine hours) recorded during the crop growing period.

Experimental details

The experiment of performance of combined application of nano urea and nitrogenous fertilizer on yield and nitrogen use efficiency of winter maize (Variety: DKC 9081) conducted in randomized block design of 8 treatments and 3 replications in a plot size of 21 m² area. In this

experiment we use urea (46% N) and nano urea (12% w/v) which is prepared by Shriram fertilizers private limited. Treatments details are like that: T_1 (Control), T_2 (100% Urea), from T_3 to T_5 comprised of 100%, 85%, 70% Urea, combined with 2.5 ml/l of nano urea at V3 (3 leaf stage) and tasselling stage and from T_6 to T_8 comprised of 100%,

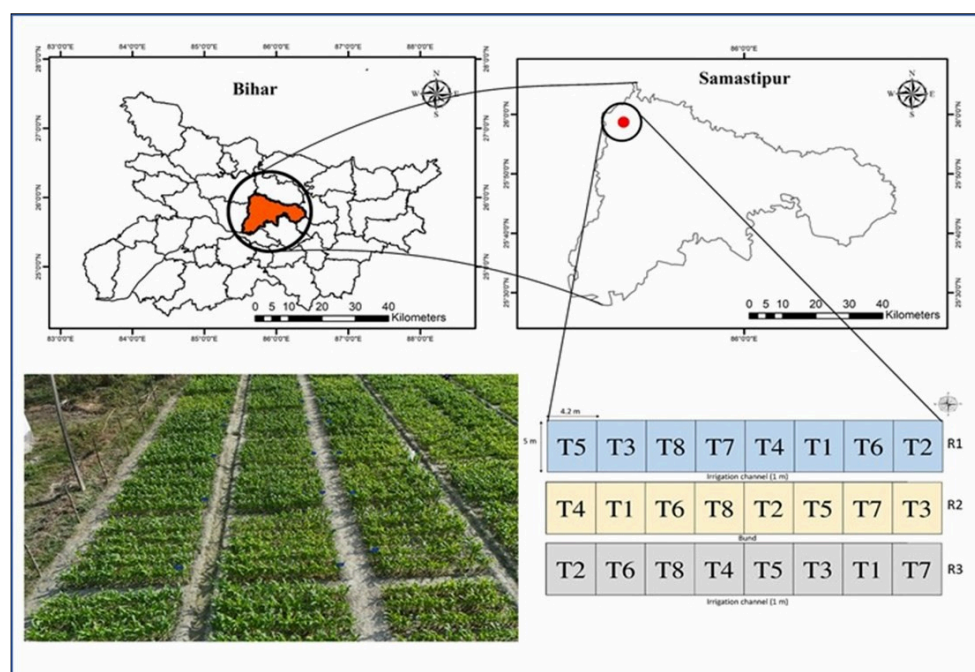


Figure 2.2. Location map of the experimental site and layout of the field experiment showing randomized allocation of treatments (T_1 – T_8) in three replications (R_1 – R_3).

85%, 70%, Urea, combined with 1.25 ml/l of nano urea at V3 (3 leaf stage) and tasselling stage. In all the treatments we apply DAP and Muriate of Potash (MOP) uniformly. In this experiment we use

180:60:40 kg/ha N: P₂O₅: K₂O as a fertilizer recommendation. Total amount of fertilizer according to each treatment described in Table 2.1.

Table 2.1. Amount of fertilizer applied to each treatment:

Treatment no.	Basal dose (kg/ha)	Top dressing (1st) (kg/ha)	Top dressing (2nd) (kg/ha)	Nitrogen by nano urea (g/ha)	Total amount of nitrogen (kg/ha)
T ₁	0	0	0	0	0
T ₂	60	60	60	0	180
T ₃	60	60	60	300	180.3
T ₄	51	51	51	300	153.3
T ₅	42	42	42	300	126.3
T ₆	60	60	60	150	180.15
T ₇	51	51	51	150	153.15
T ₈	42	42	42	150	126.15

Soil analysis

For soil analysis we collected soil sample from 15 cm depth in a zig-zag pattern from 4 places of each treatment and replication followed by air drying and sieving through 2 mm of collected soil sample. Then the processed sample gone through analysis of pH and EC (dS/m) using standard protocols (Jackson, 1973) [8], soil organic carbon (%) (Walkley *et al.*, 1934) [9], available nitrogen by using alkaline permanganate method (Subbiah *et al.*, 1956) [10], available phosphorus by using sodium bi-carbonate method (NaHCO₃) (Olsen *et al.*, 1954) [11], available potassium by using ammonium acetate (NH₄OAc) method (Merwin *et al.*, 1951) [12].

Plant nitrogen analysis

For plant analysis, samples were oven-dried followed by grinding. The processed sample gone through modified micro-Kjeldahl method following di-acid (H₂SO₄–salicylic acid) digestion (Piper, 1966) [13].

Nitrogen use efficiency

Nitrogen use efficiency was assessed using agronomic efficiency (AE), physiological nitrogen uses efficiency (PNUE), apparent recovery efficiency (ARE), and nutrient harvest index (NHI). AE was calculated as the increase in grain yield per unit of nitrogen applied (Grain yield in treated plot (kg/ha) – Grain yield in control (kg/ha))/N applied (kg/ha), while PNUE was expressed as the increase in grain yield per unit increase in nitrogen uptake (Grain yield in treated plot (kg/ha) – Grain yield in control (kg/ha))/(N uptake in treated plot (kg/ha) – N uptake in control (kg/ha)). ARE (%) was computed as the

proportion of applied nitrogen recovered by the crop [(N uptake in treated plot (kg/ha) – N uptake in control (kg/ha))/N applied (kg/ha) × 100], and NHI (%) was calculated as the ratio of nitrogen accumulated in grain to total nitrogen uptake by the plant (N uptake in grain (kg/ha)/Total N uptake in plant (kg/ha)) × 100.

Statistical analysis

Statistical analysis and graphical representation was carried out using the AgroR and ggplot2 package respectively in R. Treatment means are compared with 5% significance level using LSD and SEM (±).

Result and discussion

Soil parameter: Data on post-harvest soil properties present on table no 3.5. Although post-harvest soil properties such as pH, EC (dS/m), soil organic carbon (%), and available nitrogen, phosphorus, and potassium (kg/ha) did not differ significantly among treatments, a numerical trend was evident. Post-harvest available nitrogen status was higher under T₃ (100% Urea + 2 foliar sprays of nano urea @ 2.5 ml/l), whereas available phosphorus and potassium were relatively higher under T₁ (control). Post-harvest available N was highest under T₃ due to adequate nitrogen supply, while T₁ (control) drew on native soil reserves and recorded the lowest residual N, consistent with Upadhyay *et al.* (2023) and Gopinath *et al.* (2025) [14]. As P and K were applied uniformly across treatments, residual differences reflected crop uptake alone higher-yielding treatments removed more and left lower residues, while T₁, with the least biomass, retained the highest residual P and K.

Table 3.5. Post-harvest soil nutrient status as influenced by nano urea and conventional nitrogen management in winter maize

Treatment	Aval. N (kg/ha)	Aval. P (kg/ha)	Aval. K (kg/ha)
T ₁	179.23a+10.95	11.72a+0.72	110.51a+6.75
T ₂	191.00a+11.62	11.24a+0.68	107.86a+6.56
T ₃	193.45a+6.97	11.14a+0.4	106.16a+3.83
T ₄	185.93a+6.53	11.31a+0.4	108.37a+3.81
T ₅	182.75a+16.24	11.44a+1.02	109.74a+9.75
T ₆	192.78a+7.79	11.19a+0.45	107.21a+4.33
T ₇	183.89a+7.66	11.32a+0.47	109.03a+4.54
T ₈	180.23a+4.16	11.51a+0.27	110.31a+2.55

Nutrient analysis in plant and nutrient use efficiency: Nutrient content (%) in plant

and nutrient uptake (kg/ha) by plant can be presented in fig 3.4 and fig 3.5 respectively. Nutrient uptake is multiplication of nutrient content (%) and yield (kg/h). T₃ (100% Urea + 2 foliar sprays of nano urea @ 2.5 ml/l) shows highest nutrient content and nutrient uptake

among all other treatments; it may be due to 100% urea provided all the nutrient of plant needed with that nano urea can penetrate easily plant system. T₂ (100% Urea), T₄ (85% Urea + 2 foliar sprays of nano urea @ 2.5 ml/l), T₆ (100% Urea + 2 foliar sprays of nano urea @ 1.25 ml/l) are statically at par with that; means nano urea can compensate 15% conventional urea consistent with Gopinath *et al.* (2025) [14].

^{14]}. Data on nutrient use efficiency presented on table 3.6 where AE, PE, ARE, NHI represent like

agronomic efficiency, physiological efficiency, apparent recovery efficiency and nutrient harvest index respectively.

Table 3.6. Effect of different treatment on nutrient use efficiency (NUE) in winter maize:

Treatment	AE	PE	ARE	NHI (%)
T_1	-	-	-	57.69b+3.52
T_2	29.54ab+1.80	59.89a+3.64	0.49b+0.03	67.61ab+4.11
T_3	33.93a+1.22	57.19ab+2.06	0.59a+0.02	68.82a+2.48
T_4	32.3ab+1.13	53.47abc+1.88	0.6a+0.02	68.46ab+2.4
T_5	30.39ab+2.70	48.32c+4.29	0.63a+0.06	69.02a+6.13
T_6	31.06ab+1.26	53.91abc+2.18	0.58a+0.02	68.3ab+2.76
T_7	29.6ab+1.23	53.24abc+2.22	0.56ab+0.02	68.33ab +2.84
T_8	28.14b+0.65	50.49bc+1.17	0.56ab+0.01	67.83ab +1.57

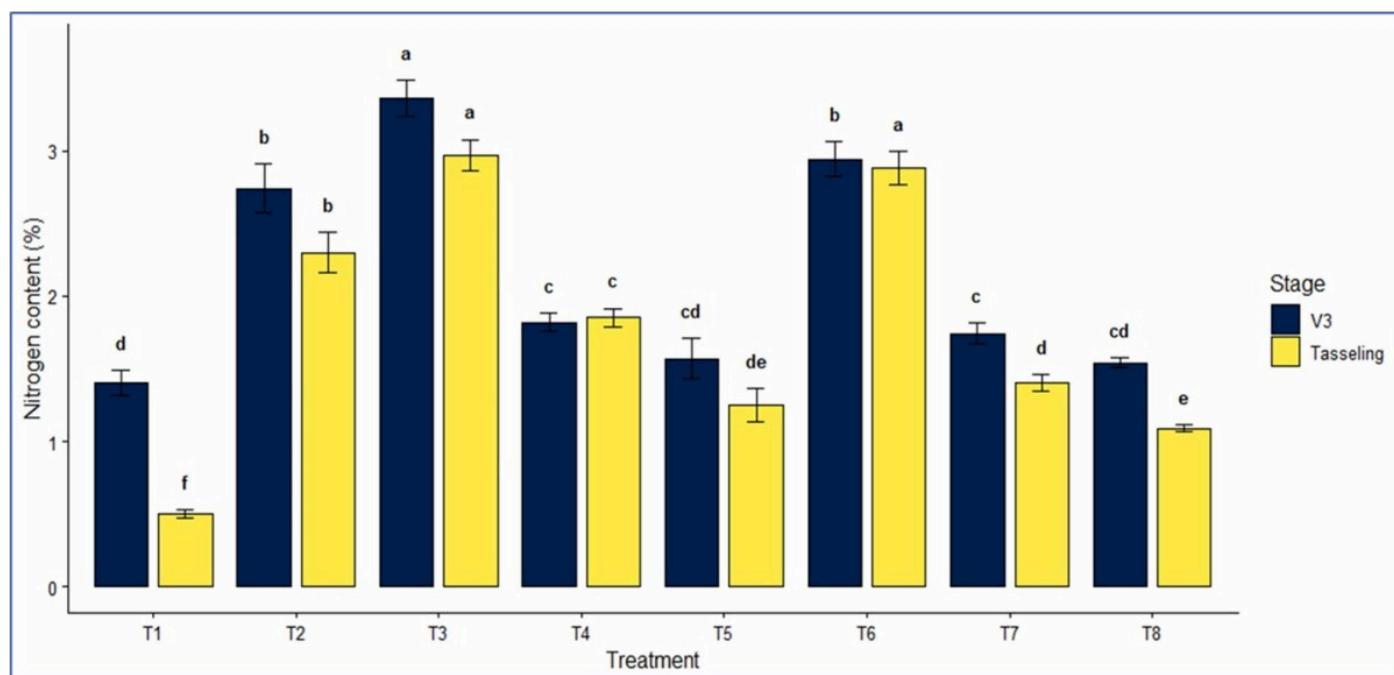


Figure 3.5. Effect of treatments on nutrient uptake (kg/ha) and nutrient content (%) of winter maize. Error bars denote $\pm$ S.E; bars with the same letter do not differ significantly at $P \leq 0.05$ (LSD).

Agronomic efficiency was highest under T_3 (100% Urea + 2 foliar sprays of nano urea @ 2.5 ml/l) and remained statistically at par with all other treatments except T_8 (70% Urea + 2 foliar sprays of nano urea @ 1.25 ml/l), likely attributable to the higher grain yield recorded under this treatment. Physiological efficiency was highest under T_2 (100% Urea) and was statistically at par with all treatments except T_5 (70% Urea + 2 foliar sprays of nano urea @ 2.5 ml/l) and T_8 , which may be due to limited sink capacity restricting the conversion of additional nitrogen uptake into extra grain yield. Apparent recovery efficiency was highest under T_5 , likely because the reduced conventional urea dose minimized nitrogen losses to the environment, allowing a greater proportion of applied nitrogen to be recovered by the plant; which is consistent with thakur *et al.* (2022). Nutrient harvest index did not differ significantly among treatments, though it was numerically highest under T_5 .

Correlation between various variables and principal component analysis

Correlation analysis among yield and its attributing parameters, along with nitrogen use efficiency indices, is presented in Figure 3.6. Grain yield showed a highly significant positive correlation with SPAD

value ($r = 0.822$), nitrogen uptake ($r = 0.824$), agronomic efficiency ($r = 0.809$), and apparent recovery efficiency ($r = 0.738$), and significant positive correlation with leaf N content ($r = 0.761$) and harvest index ($r = 0.607$). Among the NUE indices, nitrogen uptake showed the strongest association with agronomic efficiency ($r = 0.964$) and apparent recovery efficiency ($r = 0.920$), while harvest index was most strongly correlated with nutrient harvest index ($r = 0.943$). Principal component analysis explained 89.9% of total variance ($PC_1 = 78\%$, $PC_2 = 12\%$; KMO = 0.64), with PC_1 driven by yield, SPAD, leaf N, N uptake, AE, and ARE. T_3 , T_6 , and T_2 clustered on the positive PC_1 axis, reflecting superior overall performance, while T_1 (control) was clearly separated on the negative axis, and T_8 occupied an intermediate position. This separation confirms the consistently poor performance of the unfertilized control, while the clustering of T_4 and T_2 at sample place; suggest that we can replace 15% conventional urea without reducing the yield.

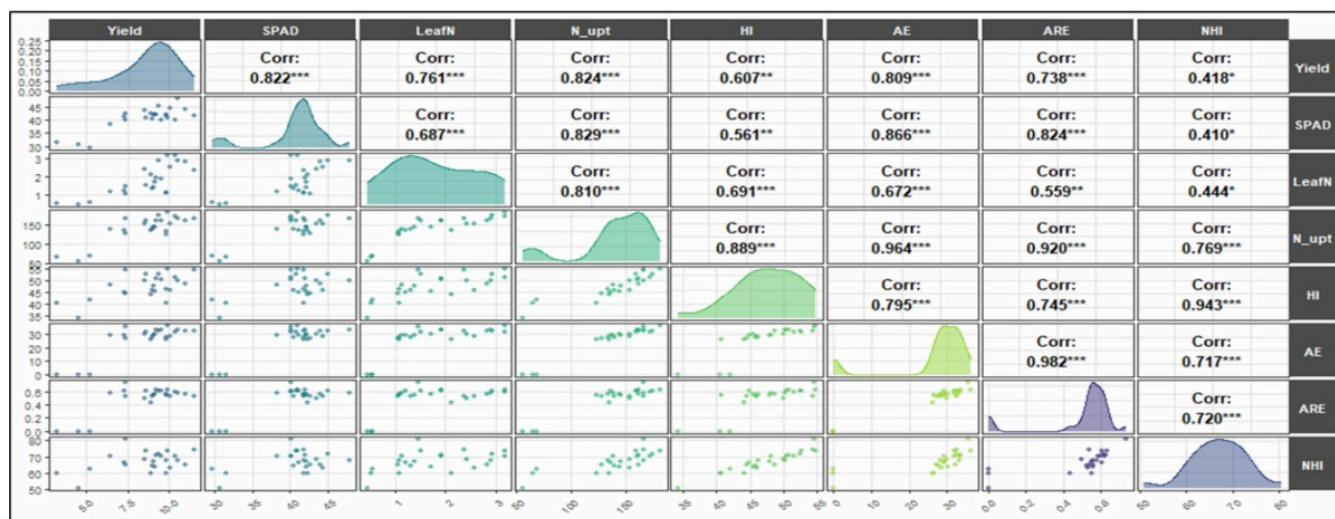


Figure 3.6. Pearson correlation matrix among growth, yield, and nitrogen use efficiency parameters under nano urea and conventional urea treatments. Diagonal panels show the density distribution of each variable; lower-triangle panels show pairwise scatter plots; upper-triangle panels show Pearson correlation coefficients (r). Asterisks denote significance level: * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$. SPAD = chlorophyll meter reading; LeafN = leaf nitrogen content (%); N_{upt} = total nitrogen uptake (kg ha^{-1}); Yield = grain yield (t ha^{-1}); HI = harvest index (%); AE = agronomic efficiency ($\text{kg kg}^{-1} \text{N}$); ARE = apparent recovery efficiency (%); NHI = nutrient harvest index (%).

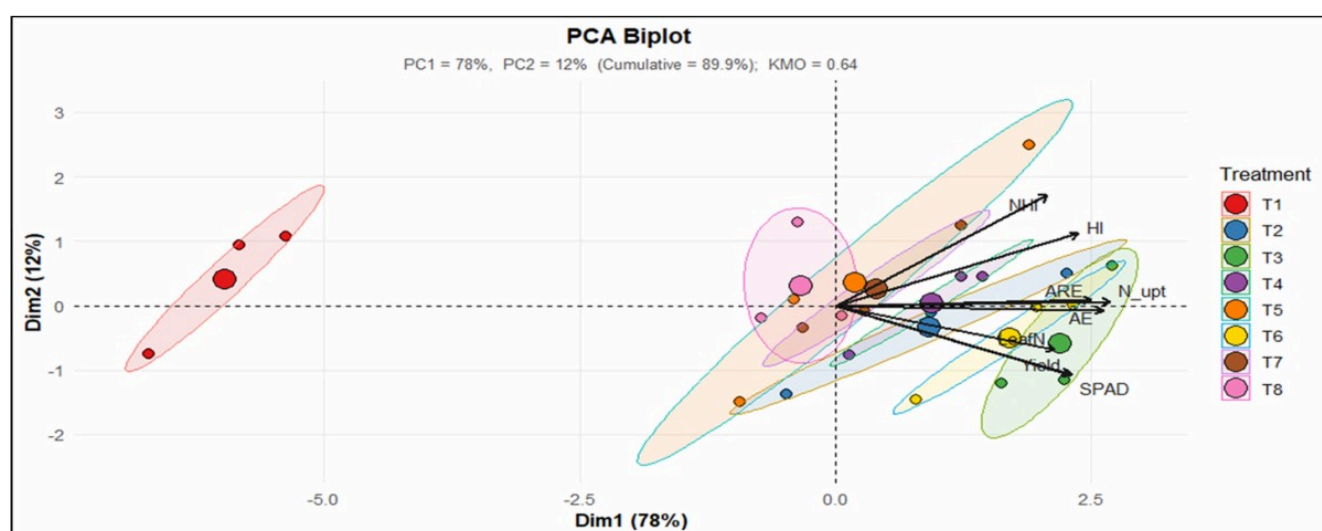


Figure 3.7. Principal component analysis (PCA) biplot of growth, yield, and nitrogen use efficiency parameters as influenced by combined application of urea and nano urea in rabi maize. PC_1 and PC_2 explained 78.0% and 12.0% of the total variance, respectively (cumulative variance = 89.9%; KMO measure of sampling adequacy = 0.64). Coloured points represent individual replications grouped by treatment (T_1 – T_8), with larger points indicating treatment centroids and shaded ellipses representing 95% confidence regions. Arrows represent loading vectors of the original variables; arrow length is proportional to that variable's contribution to the principal components, and direction indicates the strength/sign of correlation with each axis. SPAD = chlorophyll meter reading; LeafN = leaf nitrogen content (%); N_{upt} = total nitrogen uptake (kg ha^{-1}); Yield = grain yield (t ha^{-1}); HI = harvest index (%); AE = agronomic efficiency; ARE = apparent recovery efficiency; NHI = nutrient harvest index.

Conclusion

This study evaluated the effects of combined nano urea and conventional urea application on nutrient uptake of winter maize. T_3 (100% urea + two foliar sprays of nano urea @ 2.5 ml/l) recorded the highest nutrient uptake and content, and the highest agronomic efficiency (statistically at par with all treatments except T_8). T_4 (85% urea + 2.5 ml/l nano urea) remained at par with T_3 for nutrient uptake and content, and clustered with T_2 and T_3 on the positive PC_1 axis in the PCA biplot, reflecting comparable overall performance. This indicates that nano urea can substitute up to 15% of conventional urea without a significant reduction in yield, nutrient status, or profitability. Post-harvest soil nutrient status did not differ significantly among treatments. Collectively, these results support nano urea as a viable component of integrated nitrogen management for improving nitrogen use

efficiency while reducing dependence on conventional fertilizer, though long-term studies on its environmental and soil-health implications are warranted before large-scale adoption.

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