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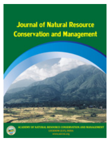

Soil Property Responses to Integrated Application of Urea and Nano Urea in Tarai Region of Uttarakhand

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ABSTRACT

A field experiment was conducted to evaluate the effect of integrated nitrogen management using conventional urea and nano urea on post-harvest soil physico-chemical properties under the Tarai conditions of Uttarakhand. The experiment was laid out in a Randomized Block Design with three replications and eight treatments comprising different levels of basal urea application (100%, 75% and 50% of recommended dose of nitrogen) combined with foliar sprays of nano urea. The results indicated that the integrated application of urea and nano urea significantly enhanced soil nutrient status, whereas soil bulk density, pH and electrical conductivity remained largely unaffected after rice harvest. The highest available nitrogen (233.74 kg ha^{-1}), phosphorus (13.55 kg ha^{-1}) and potassium (214.05 kg ha^{-1}) were recorded under the treatment receiving 100% RDN along with two foliar sprays of nano urea (T_2), while the lowest values (204.98 kg ha^{-1} N, 10.78 kg ha^{-1} P and 178.43 kg ha^{-1} K) were observed in the absolute control (T_8). Post-harvest soil organic carbon content was maximum (0.79%) under crop residue incorporation combined with two foliar sprays of nano urea. Overall, sole application of urea or nano urea was less effective in improving soil nutrient availability compared to their integrated use. Incorporation of crop residues along with foliar application of nano urea proved more effective in enhancing soil organic carbon. The application of nano urea helped minimize nitrogen losses and exerted a positive influence on soil properties.

Keywords: Nano urea, Urea, Integrated nutrient management, Rice crop, Soil properties

INTRODUCTION

The Tarai belt of northern India is a highly productive agro-ecological region characterized by deep alluvial soils, high organic matter content and intensive cropping systems such as rice-wheat. However, the region also experiences high rainfall and shallow groundwater tables and suitable for rice cultivation. In India, the harvested area for rice was estimated 47.83 million hectares with a production of 149.07 million tonnes (STATISTA, 2025). However, global rice production during 2024-25 is 555.6 million tonnes (FAO, 2025). Rice is the staple carbohydrate source for over half of the world's population and it is predominantly grown in tropical and subtropical regions (Khush, 2013). Additionally, the cultivation of rice (*Oryza sativa* L.) leads to periodic shifts in soil conditions (anaerobic during the flooded rice and aerobic during the *rabi* season) which significantly influence soil nutrient dynamics and fertilizer efficiency. Similar nutrient–microbial interactions under variable moisture and temperature regimes were reported by Bhardwaj *et al.,* (2020), demonstrating strong linkages between soil biological activity and nitrogen transformations.

Nitrogen is the most essential nutrient for plant growth, playing a critical role in the formation of nucleic acids, enzymes, amino acids, and proteins necessary for physiological functions (Marschner, 1995; Chejara *et al.,* 2021). The influence of nitrogen management on soil carbon fractions and biological responses has also been highlighted by Bhardwaj *et al.,* (2019), emphasizing the ecological role of balanced nutrient supply.

In India, nitrogenous fertilizers, especially urea, are overused due to heavy subsidies, leading to injudicious application rates (Sharma and Thaker, 2011; Ladha *et al.,* 2005). Urea has high nitrogen content (46%) and is compatible with other inputs, its field nitrogen use efficiency (NUE) is only 30-35% (Kumar *et al.*, 2024b). Field-scale variations in nitrogen use efficiency under different nutrient schedules were also observed by Bhardwaj *et al.,* (2020), particularly in rice–wheat systems.

The remaining nitrogen is lost through leaching, ammonia volatilization, and nitrous oxide emissions, especially in waterlogged and alkaline soils, causing environmental pollution (Mahmud *et al.,* 2021; Fageria *et al.,* 2010; Zhao *et al.,* 2021). Environmental impacts associated with nitrogen losses under contrasting water management conditions were similarly noted by Singh *et al.,* (2014), who reported reductions in water and nitrogen productivity.

The anaerobic environment of flooded rice fields contributes to nitrogen losses *via* ammonia volatilization and denitrification (Chen *et al.,* 2024). Moisture–nutrient interactions affecting nitrogen transformation processes were further supported by Bhardwaj *et al.,* (2015), highlighting the sensitivity of nitrogen dynamics under variable hydrological conditions. Subsoil compaction caused by puddling in flooded rice fields reduces nutrient uptake in the succeeding crops, with nitrogen, phosphorus and potassium uptake decreasing by 12-35%, 17-27%, and 24%, respectively (Ishaq *et al.,* 2001). Changes in soil carbon and microbial functioning under varying soil physical conditions have also been documented by Thakur *et al.,* (2020), explaining reduced nutrient availability in compacted soils. As a result, farmers apply larger quantities of fertilizers to fulfil crop nutritional needs, which can lead to adverse environmental impacts (Kumar *et al.*, 2024a). Kushwaha *et al.,* (2020) similarly observed that nutrient-induced microbial stress can contribute to substantial nitrogen losses and soil degradation. To reduce losses and improve efficiency, nanotechnology plays an important role. India became the first country to commercially produce nano-urea, with IFFCO investing Rs. 175 crores in its manufacture. A 500 ml bottle of nano-urea can replace a 45 kg bag of conventional urea and is 10% cheaper. Its shelf life is 2 years. Nano-urea, developed by IFFCO at the Nano Biotechnology Research Center in Kalol, Gujarat, is a 4% nitrogen liquid fertilizer that comes under the Fertilizer Control Order, 1985 (Kumar *et al.,* 2021; Yamuna *et al.,* 2023). It is an environmentally adoptable nitrogen fertilizer, cheaper, convenient to store and has the potential to transform agriculture, serving as a valuable innovation tool for precision farming (Meena *et al.,* 2021; Danu *et al.,* 2022; Bhardwaj *et al.*, 2025). Additional evidence on nutrient–environment interactions in agricultural soils has also been presented by Bhardwaj *et al.,* (2021), affirming the need for efficient nutrient delivery systems such as nano-urea.

MATERIALS AND METHODS

The field experiment was conducted from June 2023 to October 2024 at the B1 block of the Norman E. Borlaug Crop Research Centre, G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand (29°N, 79°E; 243.8 m amsl) in the Tarai region, under the All India Coordinated Research Project. The region experiences a sub-humid subtropical climate with hot summers and cool winters, receiving about 1400 mm of annual rainfall, of which 85-90% occurs during the southwest monsoon (June-September).

The experiment was laid out in a randomized block design with three replications and eight treatments involving different levels of basal urea (100, 75 and 50% RDN) and foliar application of nano urea. The experimental soil (0-15 cm) was silty clay in texture (9.24% sand, 38.31% silt and 52.45% clay), neutral in reaction (pH=7.36), with electrical conductivity of 0.35 dS m^{-1}, bulk density of 1.37 Mg m^{-3} and organic carbon content of 0.68%. The soil was low in available nitrogen (198 kg ha^{-1}) and phosphorus (10.57 kg ha^{-1}) and medium in potassium (176 kg ha^{-1}).

Sources of Nutrients

A recommended fertilizer dose of 120:60:30 kg N:P:K ha^{-1} was applied. Phosphorus (SSP) and potassium (MOP) were applied as basal doses, while nitrogen (urea) was given in splits. Nano urea (4 mL L^{-1}) was applied as a foliar spray at tillering and panicle initiation stages. Foliar application of nano urea was done with urea in T_2, T_3 and T_5 and as a sole spray in T_6 and T_7. In T_7, wheat residue (0.7% N, 0.24% P_2O_5, 1.25% K_2O) were incorporated at 12.5 kg plot^{-1} (dry weight), 15 days before transplanting to enhance nutrient supply.

Sampling and Analysis

Soil samples were collected from 0-15 cm depth before planting and after harvest, shade-dried, sieved (2 mm) and analyzed for physical and chemical properties using standard procedures (Bouyoucos, 1936 and Jackson, 1973). Physical properties such as soil texture and bulk density were determined by the hydrometer and core methods, respectively. Chemical analyses included pH, EC, organic carbon, available N (Subbiah and Asija, 1956), available P (Olsen *et al.,* 1954) and available K (Perur *et al.,* 1973). Data were statistically analysed using ANOVA as per Gomez and Gomez (1984) at a 5% significance level.

RESULTS AND DISCUSSION

After the harvest of rice, it was observed that soil bulk density, pH, and electrical conductivity were not significantly affected by the application of urea, nano urea, or residue incorporation (Fig. 1). It was found that the lowest bulk density was recorded under T_7 (1.33 Mg m^{-3}), which was statistically at par with T_3, T_5, and T_6 and significantly lower than the absolute control (T_8: 1.36 Mg m^{-3}), indicating a slight reduction compared to the initial bulk density (1.37 Mg m^{-3}). It was further observed that soil pH after harvest ranged from 7.28 to 7.34, with the highest value in T_8, which was statistically comparable to T_6, T_7, and T_3, while slightly lower values were recorded in T_1 and T_2; however, the differences among treatments were non-significant. Similarly, it was found that soil electrical conductivity varied from 0.31 to 0.34 dS m^{-1}, with relatively higher values in T_1, T_2, T_5, and T_7 and lower values in T_3 and T_6, though these variations were non-significant, indicating minimal influence of nutrient management practices on soil salinity.

Soil organic carbon (SOC) content after crop harvest varied from 0.70 to 0.79% across the treatments. A significant enhancement in SOC was observed under T_2, which recorded the highest value (0.79%) compared to the initial SOC content of 0.68%, indicating an improvement in soil carbon status due to this treatment. In contrast, the SOC values under T_1, T_6, and T_8 remained statistically at par with each other and showed only marginal increases over the initial level. The observed variations in SOC among treatments are illustrated in Fig. 2.

Soil Available N, P and K

After rice harvest, the highest soil available nutrients were recorded in T_2, with N (233.74 kg ha^{-1}), P (13.55 kg ha^{-1}), and K (214.05 kg ha^{-1}), all of which were statistically at par with T_1 [N (231.57 kg ha^{-1}), P (13.37 kg ha^{-1}) and K (212.00 kg ha^{-1})], whereas the lowest availability of N, P and K was observed in T_8, recording 204.98 kg ha^{-1} N, 10.78 kg ha^{-1} P and 178.43 kg ha^{-1} K (Table 1). The higher nutrient availability in T_1 and T_2 may be attributed to the efficient and synchronized nutrient supply from urea and nano urea, which met crop demand at critical growth stages and minimized nutrient losses, resulting in improved residual soil fertility after rice harvest.From the experiment it was concluded that there was no significant impact of nano urea with or

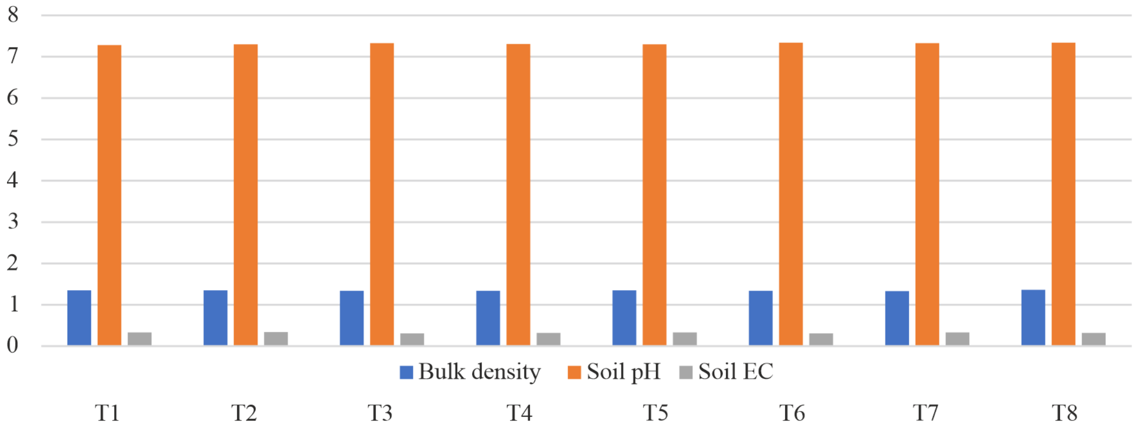

Fig. 1. Effect of urea and nano urea on bulk density (Mg m^{-3}), pH, EC (dS m^{-1}) after harvesting of rice crop

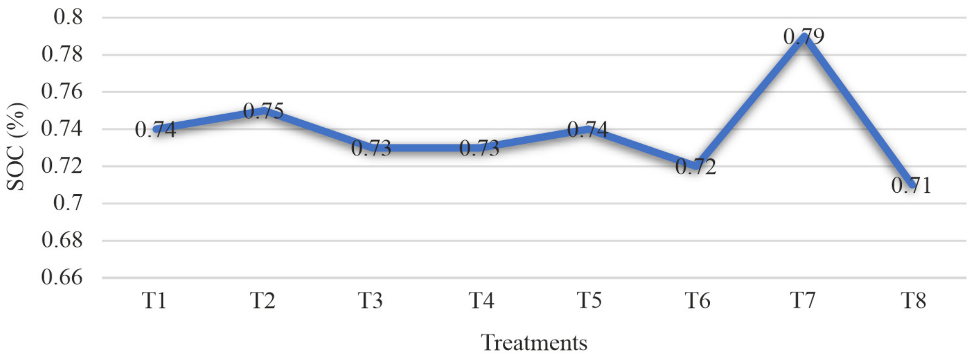

Fig. 2. Effect of urea and nano urea on soil organic carbon (%) after harvesting of rice crop

Table 1. Effect of urea and nano urea on soil available N, P and K

Treatments	N (kg ha^{-1})	P (kg ha^{-1})	K (kg ha^{-1})
T_1: 100% RDN	231.57	13.37	212.00
T_2:100% RDN + 2 Nano urea spray @ 4 mL L^{-1} at T and PI	233.74	13.55	214.05
T_3: 50% RDN + 2 Nano urea spray @ 4 mL L^{-1} at T and PI	218.44	12.40	190.67
T_4: 75% RDN	223.85	12.81	196.67
T_5: 75% RDN + 2 Nano urea spray @ 4 mL L^{-1} at T and PI	225.43	12.93	199.13
T_6: 2 Nano urea spray @ 4 mL L^{-1} at T and PI	208.15	11.80	180.30
T_7: 2 nano urea spray @ 8 mL L^{-1} at T and PI + crop residue (5t ha^{-1})	212.56	12.02	185.27
T_8: absolute control	204.98	10.78	178.43
SEm ±	1.35	0.08	1.57
C.D. (5%)	4.10	0.24	4.78

without urea on soil bulk density, pH, soil electrical conductivity. Even there was non-significant impact was observed in soil organic carbon but the slightly higher values were recorded in T_7 because of incorporation of wheat crop residue. The improvement in SOC is attributed to enhanced biomass production and incorporation of crop residues, which undergo microbial decomposition forming stable organic compounds, stimulating microbial activity and improving soil structure. This enhances carbon sequestration and soil fertility, consistent with findings by Raun *et al.* (1998), Halvorson and Reule (1999).

The nutrient content in soil increased on increasing the higher nutrient application. The higher N in T_1 and T_2 is due to efficient nitrogen supply from urea and nano urea, which met crop demand at critical stages and minimized N losses. Intermediate values in T_3, T_4, T_5 and T_7 indicate that nano urea partially compensated for reduced basal N and crop residue improved nitrogen availability. The lowest N in T_8 reflects the absence of N fertilization. These observations are consistent with Zheng *et al.* (2017) and Namasharma *et al.* (2023). The increase in P in T_1 and T_2 is attributed to adequate nitrogen supply from urea and nano urea, which supports better root growth and microbial activity, enhancing phosphorus uptake. Lower P in T_3, T_6, and T_7 is likely due to nitrogen deficiency limiting root development and nutrient cycling (Fageria, 2010). Nano urea's small particle size and slow-release nature improve nitrogen use efficiency, reduces N losses, and helps maintain soil P availability (Naderi *et al.,* 2013; Subramani *et al.,* 2023 and Tarafdar *et al.,* 2014). The higher K in T_1 and T_2 is due to the combined application of basal urea and nano urea, which enhanced nitrogen availability, root growth, and microbial activity, improving K uptake. Lower K in T_3, T_6, and T_7 resulted from insufficient nitrogen in reduced or sole nano urea treatments. Nano urea's small particle size and slow-release nature also helped maintain K availability (Namasharma *et al.,* 2023).

CONCLUSION

The study revealed that the application of nano urea, either alone or in combination with conventional urea, had no significant effect on soil bulk density, pH, and electrical conductivity under

Tarai conditions of Uttarakhand. Soil organic carbon showed a non-significant response; however, slightly higher values were observed with wheat residue incorporation, indicating the role of residue recycling in improving soil carbon status. Soil nutrient availability increased with higher nutrient application rates, with the highest available N, P, and K recorded under integrated application of full recommended nitrogen through urea along with foliar sprays of nano urea. Treatments receiving reduced basal nitrogen showed intermediate nutrient levels, indicating partial compensation by nano urea, while the lowest values were recorded in the absolute control. Overall, integrated use of urea and nano urea proved superior to their sole application in enhancing soil nutrient status, and nano urea contributed to improved nitrogen use efficiency and reduced nitrogen losses.

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