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Impact of nano urea and nitrogen optimization on growth and nutrient uptake in chickpea (*Cicer arietinum* L.)

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Abstract
This study evaluated the effects of nano-urea on growth, nutrient uptake, and nitrogen use efficiency (NUE) in chickpea (*Cicer arietinum* L.) under controlled pot culture conditions. The experiment was conducted in a shade net house at the Department of Soil Science, Dr. PDKV, Akola, during the Rabi season of 2022-23, utilizing a Completely Randomized Design (CRD) with seven treatments, each replicated three times. Black Vertisol soil, characterized by low nitrogen, high phosphorus, moderate potassium, near-neutral pH, and medium organic carbon, was used. Application of nano-urea at 4 ml L^{-1} during flowering and pod development significantly increased plant height, branch number, root length, root dry weight, and total dry matter accumulation. The combination of recommended dose of fertilizer (RDF) and nano-urea maximized nitrogen, phosphorus, and potassium uptake in chickpea, comparable to other RDF-nano-urea treatments. Post-harvest soil analysis revealed that the highest residual levels of nitrogen, phosphorus, and potassium were maintained in the RDF with two nano-urea foliar sprays treatment, indicating effective nutrient retention. Nitrogen use efficiency analysis showed that reducing nitrogen fertilizer by 50% with two nano-urea foliar applications resulted in soil nitrogen mining, whereas treatments with RDF alone or combined with nano-urea demonstrated excess nitrogen supply. A 25% reduction in nitrogen, supplemented with two foliar applications of IFFCO nano-urea, was optimal for balancing chickpea nitrogen demand with efficient nutrient utilization. These findings highlight nano-urea's potential in sustainable chickpea cultivation by reducing chemical fertilizer requirements without compromising plant growth or soil nutrient status.

Keywords: Nano-urea, chickpea (Cicer arietinum L.), nitrogen use efficiency (NUE), nutrient uptake

Introduction

Chickpea (*Cicer arietinum* L.), commonly known as gram, chana, Bengal gram, or garbanzo bean, is a self-pollinated, diploid, annual legume (pulse) with short, hairy pods, usually containing two seeds. It belongs to the family Fabaceae and subfamily Faboideae. Chickpea is valued for its nutritional content, containing 21.1 percent protein, 61.5 percent carbohydrates, and 4.5 percent fat. It is also rich in calcium, iron, and niacin.

Nanotechnology, the science of manipulating materials at the nanoscale, holds promising applications in agriculture, including in fertilizers, pesticides, herbicides, and growth regulators. Nano fertilizers are created by encapsulating plant nutrients within nano materials, applying thin nano coatings to nutrients, and delivering them as nano-sized emulsions. Nano pores and stomatal openings in plant leaves facilitate the uptake of nano materials, allowing them to penetrate deeply into leaves and enhancing nutrient use efficiency. Nano fertilizers may regulate the release of nutrients and deliver the correct quantity of nutrients required by the crops in suitable proportion and promote productivity while ensuring environmental safety (De Rosa *et al.*, 2010) [4].

Nano urea contains nanoscale nitrogen particles (30-50 nm), which have a surface area 10,000 times larger and particle count 55,000 times higher than a typical 1 mm urea prill. These nano nitrogen particles, with a pore size of around 20 nm, easily penetrate cell walls and reach the plasma membrane, while larger particles (30-50 nm) can pass through stomatal pores and be transported via phloem cells. Consequently, the foliar application of nano-scale fertilizers leads to more efficient absorption and penetration (Kumar *et al.*, 2021) [6].

Materials and Methods
Considering the nature of the experiment, a pot culture experiment was conducted in a shade net house at the Department of Soil Science, Dr. PDKV, Akola. Akola has a semi-arid climate, with most rainfall occurring during the southwest monsoon season from June to September. The average monthly maximum temperature reaches 42.6 °C in May, while the minimum temperature drops to 10.3 °C in December.

The soil used in the pot culture experiment was black soil collected from the Central Research Station, Dr. PDKV, Akola, and classified as Vertisols. A composite initial soil sample was collected during pot filling and analyzed to determine the initial soil fertility status. The soil was low in available nitrogen, high in available phosphorus, moderately high in available potassium, near neutral in pH, free from soluble salts, and had medium organic carbon content. The experiment was arranged in a Completely Randomized Design (CRD) with three replications. The main objective was to study the growth, nutrient uptake, and nitrogen use efficiency of chickpea under nano urea treatments. The treatments were as follows:

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Treatment details	Acronyms
Absolute control	AC
100% RDF application	RDF
50% N + recommended dose of P & K fertilizer through soil application + foliar application of nano urea @ 4 ml L^{-1} at flowering and pod development stages	50N + RDPK + NU @ F&P
75% N + recommended dose of P & K fertilizer through soil application + foliar application of nano urea @ 4 ml L^{-1} at flowering and pod development stages	75N + RDPK + NU @ F&P
RDF + foliar application of nano urea @ 4 ml L^{-1} at flowering stage	RDF + NU @ F
RDF + foliar application of nano urea @ 4 ml L^{-1} at pod development stage	RDF + NU @ P
RDF + foliar application of nano urea @ 4 ml L^{-1} at both flowering and pod development stages	RDF + NU @ F&P

Growth observations, including plant height, number of branches, root length, root dry weight, and dry matter accumulation, were recorded. Representative soil and plant samples were collected from each pot after the chickpea harvest and analyzed for chemical properties, nutrient content, and nutrient uptake.

Results and Discussion
Effect of Nano-Urea on Growth and Yield Performance of Chickpea
The impact of nano-urea on the growth parameters of chickpea was assessed through measurements of plant height and branch number at 30 and 60 days after sowing (DAS). As shown in Table 1, the application of RDF combined with foliar nano-urea at a rate of 4 ml L^{-1} during the flowering and pod development stages resulted in the highest plant height, measuring 14.90 cm at 30 DAS and 47.96 cm at 60 DAS. This treatment was statistically comparable to the RDF alone, which produced plant heights of 14.86 cm and 47.80 cm, respectively. In contrast, the absolute control treatment yielded the lowest plant heights, with values of 11.26 cm and 37.76 cm at 30 and 60 DAS, respectively. High concentrations of nanoparticle fertilizer may be better at growing plants because of their high permeability and speed, which make it easier for them to penetrate plant leaves and aid in plant growth. Nitrogen, for example, is important for building amino acids like tryptophan, which is the building block for auxins that aid in cell division and expansion, and it also has a positive effect on meristematic tissue activity and cell division (Alqader *et al*. 2020) [2].

Regarding branch development, at 30 DAS, the application of RDF alone and the combination treatments (RDF + nano-urea) produced a similar average of 2.4 branches per plant. At 60 DAS, the highest number of branches (5.5) was recorded for the RDF + nano-urea treatment, which was statistically equivalent to the RDF alone and other treatments that involved the application of nano-urea. The absolute control treatment exhibited the lowest branch numbers, measuring 1.7 at 30 DAS and 4.2 at 60 DAS. These findings corroborate the results reported by Aziz and Zrar (2021) [1], which indicate that nano-fertilizers can significantly enhance chickpea growth.

Table 1: Effect of Foliar Application of Nano-Urea on Early Growth Metrics of Chickpea at 30 and 60 Days After Sowing (DAS)

Treatments	Early Growth Metrics			
	Plant height (cm)		No of branches	
	30 DAS	60 DAS	30 DAS	60DAS
AC	11.26	37.76	1.7	4.2
RDF	14.86	47.80	2.4	5.4
50N + RDPK + NU @ F&P	14.30	42.73	1.9	4.9
75N + RDPK + NU @ F&P	14.53	45.66	2.0	5.1
RDF + NU @ F	14.80	47.70	2.3	5.3
RDF + NU @ P	14.83	47.36	2.4	5.4
RDF + NU @ F&P	14.90	47.96	2.4	5.5
SE(m)±	0.05	0.18	0.11	0.15
CD at 5%	0.16	0.57	0.36	0.46

Root Length, Root Dry Weight, and Dry Matter Accumulation
The effect of foliar application of nano-urea on root characteristics is summarized in Table 2. The treatment with RDF and nano-urea resulted in the highest root length (24.83 cm), which was comparable to the RDF treatment alone. The absolute control exhibited the shortest root length at 18.90 cm. The results are in conformity with the results obtained by Manikandan and Subramanian (2016) [7], Nair *et al*. (2012) [8]. Similarly, the dry root weight was significantly higher in the RDF + nano-urea treatment (1.07 g), compared to the control treatment, which recorded only 0.05 g. Furthermore, dry matter accumulation per plant was also maximized under the RDF + nano-urea treatment (9.17 g), reinforcing the positive impact of nano-fertilization on chickpea biomass, as supported by the findings of Sharma *et al*. (2022) [10].

Table 2: Effect of Foliar Application of Nano-Urea on Root Length, Root Dry Weight, and Dry Matter Accumulation in Chickpea at Harvest

Treatments	Root and Biomass Accumulation at Harvest		
	Root length plant^{-1} (cm)	Root dry weight plant^{-1} (g)	Dry matter accumulation plant^{-1} (g)
AC	18.90	0.05	8.12
RDF	24.73	1.06	9.14
50N + RDPK + NU @ F&P	24.13	1.02	8.87
75N + RDPK + NU @ F&P	24.16	1.04	8.94
RDF + NU @ F	24.50	1.06	9.11
RDF + NU @ P	24.30	1.06	9.12
RDF + NU @ F&P	24.83	1.07	9.17
SE(m)±	0.18	0.005	0.04
CD at 5%	0.57	0.014	0.12

Nutrient Content and Uptake of Nitrogen, Phosphorus, and Potassium

The content and uptake of nitrogen, phosphorus and potassium in chickpea are presented in Table 3. The highest nitrogen content (0.77%) and nitrogen uptake (21.17 kg ha^{-1}) were observed in the RDF + nano-urea treatment, which was statistically similar to RDF alone. The absolute control showed the lowest nitrogen values, with 0.58% content and 14.20 kg ha^{-1} uptake. The increased nitrogen uptake is attributed to the enhanced surface area and penetrative ability of nano-urea particles, facilitating greater nutrient absorption and similar findings reported by Sharma *et al*., 2022, Sahu *et al*., 2022, Barkha *et al*., 2019 [10, 9, 3]. In terms of phosphorus, all treatments except the control were comparable regarding phosphorus content and uptake. The application of RDF alone and RDF + nano-urea achieved the highest phosphorus content (0.18%) and superior uptake (4.91 kg ha^{-1}). For potassium, the highest content and uptake were similarly recorded in treatments involving nano-urea, highlighting its effectiveness in improving overall nutrient acquisition by chickpea plants.

Table 3: Effect of Foliar Application of Nano-Urea on Nitrogen, Phosphorus, and Potassium Content and Uptake in Chickpea

Treatments	Nitrogen		Phosphorus		Potassium	
	Content (%)	Uptake (kg ha^{-1})	Content (%)	Uptake (kg ha^{-1})	Content (%)	Uptake (kg ha^{-1})
AC	0.58	14.20	0.15	3.69	0.79	19.2
RDF	0.75	20.56	0.18	4.86	1.06	29.1
50N + RDPK + NU @ F&P	0.69	18.35	0.17	4.55	1.05	28.0
75N + RDPK + NU @ F&P	0.71	19.13	0.17	4.64	1.05	28.2
RDF + NU @ F	0.76	20.77	0.17	4.80	1.06	29.1
RDF + NU @ P	0.76	20.79	0.17	4.78	1.06	29.2
RDF + NU @ F&P	0.77	21.17	0.18	4.91	1.07	29.5
SE(m)±	0.01	0.40	0.005	0.16	0.007	0.17
CDat 5%	0.04	1.23	0.016	0.48	0.02	0.54

[gram per plant values converted to kilograms per hectare for easy comparison]

Residual Nutrient Status of Soil Post-Harvest

Post-harvest analysis of soil nutrients revealed a significant increase in available nitrogen, phosphorus, and potassium levels in the soil following nano-urea treatments compared to the control (Table 4). The highest residual nitrogen (232.06 kg ha^{-1}), phosphorus (36.98 kg ha^{-1}), and potassium (238.55 kg ha^{-1}) were found in the RDF + nano-urea treatment, affirming the efficacy of nano-fertilizers in enhancing soil nutrient status, obtained results are in harmony with results of Shawer and Abdalla (2019) [11].

Table 4: Residual Effect of Nano-Urea on Soil Macronutrient Status Post-Harvest

Treatments	Available Macronutrients (kg ha^{-1})		
	Nitrogen	Phosphorus	Potassium
AC	202.79	28.81	214.59
RDF	229.97	36.79	238.48
50N + RDPK + NU @ F&P	215.33	36.06	238.07
75N + RDPK + NU @ F&P	219.51	36.24	238.18
RDF + NU @ F	225.79	36.60	238.36
RDF + NU @ P	227.88	36.42	238.41
RDF + NU @ F&P	232.06	36.98	238.55
SE(m)±	2.84	0.55	0.30
CD at 5%	8.72	1.68	0.91
Initial	206.97	29.36	219.40

Nitrogen Use Efficiency (NUE)

The nitrogen recovery efficiency (RE), termed apparent nitrogen recovery, was evaluated to assess the NUE in chickpea (Table 5). The NUE values ranged from 25.42% to 31.58%. The highest efficiency was observed with the treatment that involved a 50% reduction in nitrogen alongside two applications of nano-urea. This was in contrast to the RDF treatment alone, which exhibited a nitrogen recovery of 25.44%. The results indicate that nano-urea applications not only optimize nitrogen utilization but also support the sustainability of chickpea cultivation. Nano fertilizers are known to release nutrients slowly and steadily which may assist in improving the nutrient use efficiency without any associated ill-effects (Subramanian *et al*., 2015) [12]. As suggested by Dobermann (2007) [5], the Partial Nutrient Balance (PNB) approach indicates that PNB values greater than 1 signify nutrient mining, whereas values below 1 indicate excessive nitrogen application. The data from this study suggest that the application of 75% RDF nitrogen combined with two foliar sprays of nano-urea at 4 ml L^{-1} is optimal for promoting chickpea growth while balancing nutrient uptake and enhancing NUE. Foliar application of nano fertilizer helpful to reduce 25% nitrogen dose was also reported by Upadhyay *et al*., (2023) [13].

Table 5: Nitrogen Use Efficiency (NUE) and Partial Nutrient Balance (PNB) in Chickpea under Different Nano-Urea Treatments

Treatments	$RE_{fert\ N}$ (%)	PNB [>1-Mining from soil <1-Excess of nutrient]
AC	-	-
RDF	25.44	0.82
50N + RDPK + NU @ F&P	31.58	1.39
75N + RDPK + NU @ F&P	25.42	0.98
RDF + NU @ F	25.94	0.82
RDF + NU @ P	26.02	0.82
RDF + NU @ F&P	27.18	0.82

Conclusion

The study concludes that chickpea growth parameters and nutrient uptake (N, P, and K) were significantly enhanced with the application of two foliar sprays of nano urea combined with the recommended dose of fertilizer (RDF). Additionally, a 25% reduction in nitrogen dosage, along with the recommended doses of phosphorus and potassium and two foliar sprays of nano urea, proved to be optimal for promoting growth and achieving higher nitrogen use efficiency in chickpea.

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