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Effect of foliar fertilization of nano urea under different nitrogen levels on nutrient content and uptake by summer pearl millet (*Pennisetum glaucum* L.)

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Abstract
A field experiment was conducted at the Instructional Farm, College of Agriculture, Junagadh Agricultural University, Junagadh, during the summer season of 2023 and 2024 to study the effect of foliar fertilization of nano urea under different nitrogen levels on nutrient content and uptake by summer pearl millet (*Pennisetum glaucum* L.). The experiment was laid out in factorial randomized block design (FRBD) consist of two factors and four levels of each. Among the two factor, one was different levels of nitrogen *viz*., N_1: 0%, N_2: 50%, N_3: 75% and N_4: 100% RDN (Recommended dose of nitrogen) and another was levels of nano urea foliar spray *viz*., S_1: control (water spray), S_2: 2, S_3: 3 and S_4: 4 ml L^{-1} at 35 and 55 DAS and replicated three times. The concentration of macro (N, P and K) in grain and fodder at harvest remained significantly affected due to different nitrogen levels. Nitrogen, phosphorus and potassium content in grain and their uptake by grain recorded higher under application of 90 kg N ha^{-1}, while 120 kg N ha^{-1} remained at par treatment. Whereas in case of N, P and K content in fodder and their uptake reported maximum with treatment N_4 (100% RDN) which was noted at par with 75% RDN (N_3) noted as at par one and 75% RDN with 3 ml nano urea L^{-1} at 35 and 55 DAS archived significantly higher nitrogen content and uptake, phosphorus uptake by grain and potassium uptake by grain and fodder. However, nitrogen content and uptake by fodder, phosphorus uptake by fodder recognized higher in 120 kg N ha^{-1} with 3 ml L^{-1} foliar spray nano urea (N_4S_3).

Keywords: Nano urea, nitrogen levels, foliar fertilization

Introduction
Pearl millet is commonly known in India as Bajri or Bajra. Pearl millet (*Pennisetum glaucum* L.) is also known as 'bullrush millet', originated in tropical Western Africa. It belongs to family Gramineae. The cultivated species are *Pennisetum glaucum* L. (2n=14) used for grain and fodder and *Pennisetum purpureum* (2n=28) used for green and dry fodder. It is highly cross-pollinated crop due to protogynous nature of the flowers. It is nutritionally better than many cereals as, pearl millet grain contains 9-15 per cent protein, 5-6 per cent carbohydrates and 1-2 per cent minerals and high densities of iron, zinc and more balanced amino acid profile and also rich in vitamins, thiamine and riboflavin content than maize and sorghum (Chaudhari *et al*., 2018) [1]. Grains constitute an important cattle or poultry feed. Green fodder is used either as such or is preserved as hay or silage which has proved extremely useful in dry regions.
India is the largest producer of pearl millet in world. It occupies an area of 7.57 million ha with an average production of 10.86 million tonnes and productivity of 1436 kg ha^{-1} during 2020-21. Particularly, summer pearl millet area is only 25% of total pearl millet area, but contributes 44% to the production in Gujarat. Area cover under summer pearl millet was about 0.46 million hectares with average production of 1 million tonnes and productivity of 2192 kg ha^{-1} (Anon., 2021) [2].
Nano urea contains 4.0% total nitrogen (w/v). These particles are evenly dispersed in water. Nano urea because of its small size (20-50 nm) and higher use efficiency (> 80%). When sprayed on leaves of plant (2-4ml/liter) at critical growth stages, it increases the instant provision of nutrients to the growing plant parts, increases chlorophyll formation, rate of photosynthesis,

dry matter production and thus overall growth of the plants. Nano urea (30-40 nm) can easily penetrate the stomata and easily get entered through plasmodesmata (40 nm) and subsequently take part into the metabolism by binding itself with various carrier proteins. Unused nitrogen is retained in the plant vacuole and released slowly for appropriate plant growth and development.

The combined application of conventional nitrogenous fertilizers and nano urea offers the potential to optimize nitrogen fertilization by taking advantage of the benefits of both forms of urea. The concept behind this approach is to use conventional urea for soil application, while supplementing it with foliar spray applications of nano urea. This combination aims to meet the plant's nitrogen requirements more effectively, improve NUE, and reduce nitrogen losses.

Materials and Methods

A field experiment was conducted during during the summer season of 2023 and 2024 at the Instructional Farm, College of Agriculture, Junagadh Agricultural University, Junagadh. The experimental soil was medium black calcareous, clayey in texture and slightly alkaline in reaction. The soil was found medium to low in available nitrogen (259 and 246 kg ha^{-1}), low in available phosphorus (26 and 25 kg ha^{-1}) and high in available potassium (264 and 276 kg ha^{-1}) in both seasonal years 2023 and 2024. Three times replicated experiment consisted of two factors and four levels of each. Among the two factor, one was different levels of nitrogen *viz*., N_1: 0%, N_2: 50%, N_3: 75% and N_4: 100% RDN (Recommended dose of nitrogen) and another was levels of nano urea foliar spray *viz*., S_1: control (water spray), S_2: 2, S_3: 3 and S_4: 4 ml L^{-1} at 35 and 55 DAS was laid out in factorial randomized block design (FRBD).

Results and Discussion

Effect on macro nutrient content and uptake

A) Grain

1. Nitrogen content and uptake

Effect of nitrogen levels

The nitrogen content and uptake in pearl millet grain was significantly influenced by varying levels of nitrogen fertilization (Table 1 and 2). The highest nitrogen content in grain and their uptake by grain recorded higher under application of 90 kg N ha^{-1}, while 120 kg N ha^{-1} remained at par treatment. This might be due toenhanced nitrogen assimilation and protein synthesis facilitated by optimal nitrogen availability (Fageria *et al*., 2010) [3]. The higher nitrogen uptake at 90 kg N ha^{-1} may be attributed to the enhanced availability of nitrogen, leading to increased plant metabolism and efficient nutrient assimilation (Patel *et al*., 2022) [4] as also obtained higher grain yield.

Effect of spray nano urea levels

Foliar application of nano urea significantly enhanced the nitrogen content and uptake by grain. Application of nano urea @ 3 ml L^{-1} (S_3) at 35 and 55 DAS recorded the highest nitrogen content and uptake, which was significantly superior to the control (water spray, S_1) and nano urea @ 2 ml L^{-1} (S_2). The increased nitrogen content and uptake with nano urea application can be attributed to higher N content and grain yield, its higher nitrogen use efficiency due to better absorption through leaf stomata (Yadav *et al*., 2022) [5].

Interaction effect of levels of nitrogen and spray nano urea

The interaction effect of nitrogen levels and nano urea spray on nitrogen content in fodder was found to be significant. The highest nitrogen content and uptake was recorded with the combination of 90 kg N ha^{-1} and spraying of nano urea @ 3 ml L^{-1} (S_3), which suggests a synergistic effect of basal nitrogen application and foliar nano urea spray in enhancing nitrogen assimilation efficiency.

2. Phosphorus content and uptake

Effect of nitrogen levels

The phosphorus content highest recorded in 120 kg N ha^{-1} followed by 90 kg N ha^{-1}, and the lowest in 60 kg N ha^{-1} and highest phosphorus uptake was recorded under 90 kg N ha^{-1}. This could be attributed to the low mobility of phosphorus in soil, as phosphorus availability is largely governed by soil pH, organic matter, and microbial activity rather than nitrogen fertilization alone (Sharma *et al*., 2021) [6]. Additionally, nitrogen application enhances root growth, which may lead to better phosphorus uptake, but in this study, the increments were marginal and did not reach statistical significance (Singh and Yadav, 2020) [7].

Effect of spray nano urea levels

The application of nano urea showed a non-significant effect on phosphorus content and uptake by grain. Thesecould be due to the fact that phosphorus is primarily taken up by plants in its ionic forms ($H_2PO_4^-$ and HPO_4^{2-}), and its assimilation is not directly influenced by foliar nitrogen application (Kumar *et al*., 2019) [8]. Furthermore, phosphorus is relatively immobile in soil and largely dependent on root interception and microbial mineralization, rather than nitrogen-driven mechanisms (Ali *et al*., 2022) [9]. The slight variations observed could be due to differences in root activity and phosphorus solubilization potential but it was not substantial enough to be statistically significant.

Interaction effect of levels of nitrogen and spray nano urea

The interaction effects between soil nitrogen levels and foliar nano urea (N × S) were found non-significant in phosphorus content in grain but synergistic effect of soil-applied nitrogen and foliar nano urea on phosphorus uptake. This indicates that the combined influence of these factors did not result in substantial variation in phosphorus content in pearl millet grain. translocation efficiency of phosphorus in cereal crops and its strong fixation in the soil matrix (Mandal *et al*., 2023) [10]. Additionally, foliar nano urea mainly enhances nitrogen metabolism but does not directly impact phosphorus solubilization or uptake (Bali *et al*., 2020) [11].

3. Potassium content and uptake

Effect of nitrogen levels

The highest value of potassium content and uptake by grain was recorded at 90 kg N ha^{-1} followed by 120 kg N ha^{-1}. This trend suggests that moderate nitrogen application may enhance potassium accumulation in grains, possibly due to improved nutrient uptake and translocation within the plant (Fageria *et al*., 2010) [3]. However, further increases in nitrogen levels did not show a proportional increase in potassium content, which might be attributed to nutrient antagonism or saturation effects in nutrient absorption pathways (Marschner, 2012) [12].

Effect of spray nano urea levels

The highest potassium content was observed with a foliar spray of nano urea @ 4 ml L^{-1} followed by nano urea @ 3 ml L^{-1}. The

highest potassium uptake was observed with 3 ml L^{-1}nano urea foliar spray, which was statistically at par with 4 ml L^{-1}nano urea. The slight enhancement in potassium content with nano urea application could be attributed to improved nitrogen use efficiency, which indirectly supports and it's facilitates slow and efficient nitrogen release, reducing losses and improving overall nutrient synergy in the plant system (Mahmoud *et al*., 2022) [13].

Interaction effect of levels of nitrogen and spray nano urea

The interaction between different levels of nitrogen and nano urea foliar spray foliar spray did not exhibit significant impact on potassium content in pearl millet grains. The potassium uptake was highest with the application of 90 kg N ha^{-1} along with foliar spray of nano urea at 3 ml L^{-1}. This suggests that an optimized balance between soil applied nitrogen and foliar nano urea enhances potassium absorption. Nitrogen plays a crucial role in improving potassium uptake, as it facilitates root growth and improves the expression of potassium transporter genes in plants (Sharma *et al*., 2019) [14].

B) Fodder

4. Nitrogen content and uptake

Effect of nitrogen levels

The nitrogen content and uptake in fodder was significantly influenced by different nitrogen levels applied in soil as basal and split during both years. The highest nitrogen content and uptake in fodder was recorded with 120 kg N ha^{-1}. The increase in nitrogen content and uptake with higher nitrogen application is attributed to improved nitrogen uptake efficiency and its vital role in amino acid synthesis, which ultimately enhances the nitrogen assimilation in plant tissues (Singh *et al*., 2021) [15].

Effect of spray nano urea levels

The highest nitrogen content and uptake was registered with nano urea spray @ 3 ml L^{-1} which was significantly superior to the control and lower. The improvement in nitrogen content and uptake with nano urea application is attributed to its ultra-small particle size, which enhances leaf penetration and nutrient assimilation, leading to increased nitrogen use efficiency.

Table 1: Effect of different levels of nitrogen and nano urea foliar spray on nitrogen, phosphorus and potassium content (%) in grain of summer pearl millet (Pooled data)

Treatments	Nitrogen content (%)	Phosphorus content (%)	Potassium content (%)
Levels of nitrogen (N)			
N_1: 0% RDN (0 kg ha^{-1})	1.205	0.288	0.203
N_2:50% RDN (60 kg ha^{-1})	1.445	0.281	0.209
N_3: 75% RDN (90 kg ha^{-1})	1.702	0.293	0.212
N_4: 100% RDN (120 kg ha^{-1})	1.670	0.297	0.210
S.Em.±	0.014	0.005	0.003
C.D. at 5%	0.041	NS	NS
Spray levels of nano urea (S)			
S_1: Control (Water spray at 35 and 55 DAS)	1.404	0.291	0.206
S_2: Foliar spray of nano urea @ 2 ml L^{-1} at 35 and 55 DAS	1.500	0.296	0.207
S_3: Foliar spray of nano urea @ 3 ml L^{-1} at 35 and 55 DAS	1.548	0.279	0.210
S_4: Foliar spray of nano urea @ 4 ml L^{-1} at 35 and 55 DAS	1.570	0.291	0.210
S.Em.±	0.014	0.005	0.003
C.D. at 5%	0.041	NS	NS
N X S			
S.Em.±	0.029	0.009	0.006
C.D. at 5%	0.082	NS	NS
C.V.%	4.71	8.02	7.04

Table 2: Effect of different levels of nitrogen and nano urea foliar spray on nitrogen, phosphorus and potassium uptake (kg ha^{-1}) by grain of summer pearl millet (Pooled data)

Treatments	Nitrogen uptake (kg ha^{-1})	Phosphorus uptake (kg ha^{-1})	Potassium uptake (kg ha^{-1})
Levels of nitrogen (N)			
N_1: 0% RDN (0 kg ha^{-1})	28.57	6.75	4.78
N_2:50% RDN (60 kg ha^{-1})	41.90	8.13	6.03
N_3: 75% RDN (90 kg ha^{-1})	66.07	11.24	8.17
N_4: 100% RDN (120 kg ha^{-1})	60.60	10.76	7.62
S.Em.±	1.21	0.25	0.20
C.D. at 5%	3.43	0.72	0.57
Spray levels of nano urea (S)			
S_1: Control (Water spray at 35 and 55 DAS)	41.20	8.42	5.94
S_2: Foliar spray of nano urea @ 2 ml L^{-1} at 35 and 55 DAS	49.95	9.52	6.68
S_3: Foliar spray of nano urea @ 3 ml L^{-1} at 35 and 55 DAS	53.16	9.37	7.07
S_4: Foliar spray of nano urea @ 4 ml L^{-1} at 35 and 55 DAS	52.82	9.56	6.92
S.Em.±	1.21	0.25	0.20
C.D. at 5%	3.43	0.72	0.57
N X S			
S.Em.±	2.43	0.51	0.41
C.D. at 5%	6.86	1.44	1.15
C.V.%	12.05	13.55	14.95

Interaction effect of levels of nitrogen and spray nano urea

The interaction effect of nitrogen levels and nano urea spray on nitrogen content and uptake by fodder was found to be significant. The highest nitrogen content and uptake was recorded with the combination of 120 kg N $ha^{-1}$and spraying of nano urea @ 3 ml L^{-1} (S_3), which suggests a synergistic effect of basal nitrogen application and foliar nano urea spray in enhancing nitrogen assimilation efficiency. This could be due to minor variations in climatic conditions, soil moisture, or microbial activity influencing nitrogen mineralization and uptake.

Table 3: Effect of different levels of nitrogen and nano urea foliar spray on nitrogen, phosphorus and potassium content (%) in fodder of summer pearl millet (Pooled data)

Treatments	Nitrogen content (%)	Phosphorus content (%)	Potassium content (%)
Levels of nitrogen (N)			
N_1: 0% RDN (0 kg ha^{-1})	0.463	0.146	1.239
N_2:50% RDN (60 kg ha^{-1})	0.585	0.146	1.259
N_3: 75% RDN (90 kg ha^{-1})	0.748	0.152	1.302
N_4: 100% RDN (120 kg ha^{-1})	0.773	0.151	1.270
S.Em.±	0.009	0.002	0.020
C.D. at 5%	0.027	NS	NS
Spray levels of nano urea (S)			
S_1: Control (Water spray at 35 and 55 DAS)	0.573	0.148	1.277
S_2: Foliar spray of nano urea @ 2 ml L^{-1} at 35 and 55 DAS	0.637	0.150	1.218
S_3: Foliar spray of nano urea @ 3 ml L^{-1} at 35 and 55 DAS	0.687	0.149	1.252
S_4: Foliar spray of nano urea @ 4 ml L^{-1} at 35 and 55 DAS	0.674	0.148	1.324
S.Em.±	0.009	0.002	0.020
C.D. at 5%	0.027	NS	NS
N X S			
S.Em.±	0.019	0.004	0.040
C.D. at 5%	0.053	NS	NS
C.V.%	7.19	7.07	7.71

Table 4: Effect of different levels of nitrogen and nano urea foliar spray on nitrogen, phosphorus and potassium uptake (kg ha^{-1}) by fodder of summer pearl millet (Pooled data)

Treatments	Nitrogen uptake (kg ha^{-1})	Phosphorus uptake (kg ha^{-1})	Potassium uptake (kg ha^{-1})
Levels of nitrogen (N)			
N_1: 0% RDN (0 kg ha^{-1})	22.69	5.62	47.88
N_2:50% RDN (60 kg ha^{-1})	32.70	7.02	60.56
N_3: 75% RDN (90 kg ha^{-1})	57.49	11.26	96.72
N_4: 100% RDN (120 kg ha^{-1})	64.06	11.59	97.35
S.Em.±	1.39	0.25	2.13
C.D. at 5%	3.92	0.69	6.03
Spray levels of nano urea (S)			
S_1: Control (Water spray at 35 and 55 DAS)	32.83	7.42	63.68
S_2: Foliar spray of nano urea @ 2 ml L^{-1} at 35 and 55 DAS	44.58	9.02	73.52
S_3: Foliar spray of nano urea @ 3 ml L^{-1} at 35 and 55 DAS	50.95	9.63	81.35
S_4: Foliar spray of nano urea @ 4 ml L^{-1} at 35 and 55 DAS	48.57	9.42	83.96
S.Em.±	1.39	0.25	2.13
C.D. at 5%	3.92	0.69	6.03
N X S			
S.Em.±	2.77	0.49	4.26
C.D. at 5%	7.84	1.39	12.05
C.V.%	15.35	13.56	13.80

5. Phosphorus content and uptake

Effect of nitrogen levels

Significantly higher phosphorus content in the fodder of summer pearl millet was recorded at 90 kg N ha^{-1} and higher phosphorus uptake by fodder under 120 kg N ha^{-1}. The increased phosphorus content and uptake with higher nitrogen levels can be attributed to enhanced root proliferation and improved nutrient acquisition due to the synergistic relationship between nitrogen and phosphorus. Nitrogen fertilization promotes root growth, leading to better exploration of soil phosphorus, thereby increasing its uptake by the plants (Sharma *et al*., 2019) [14].

Effect of spray nano urea levels

The application of nano urea at different concentrations did not significantly influence phosphorus content in fodder during either year or in pooled analysis. Among the different nano urea spray treatments, the application of 3 ml L^{-1} nano urea at 35 and 55 DAS recorded the highest phosphorus uptake. The increased uptake observed due to the optimized concentration of nano urea, which improves nitrogen use efficiency, subsequently increasing phosphorus assimilation. However, a further increase in nano urea concentration (S_4) didn't lead to proportionate increase in phosphorus uptake, possibly due to saturation effect or potential physiological limitations of the plant.

Interaction effect of levels of nitrogen and spray nano urea

The interaction effects of nitrogen levels and nano urea application were also found to be statistically non-significant.

The lack of significant interaction suggests that neither factor synergistically influenced phosphorus concentration in fodder.

6. Potassium content and uptake

Effect of nitrogen levels

Potassium content in the fodder of summer pearl millet did not affect significantly by different nitrogen levels. The highest potassium uptake was observed at 100% Recommended Dose of Nitrogen (120 kg N ha^{-1}). The significant increase in potassium uptake with higher nitrogen levels can be attributed to enhanced root growth and improved nutrient absorption capacity due to the synergistic effect of nitrogen on cation exchange capacity and membrane permeability. Additionally, higher nitrogen availability promotes biomass accumulation, which in turn increases potassium demand and uptake (Kumar *et al*., 2019) [8].

Effect of spray nano urea levels

Application of nano urea through foliar spray at 35 and 55 DAS significantly influenced potassium content in fodder, though the differences remained statistically non-significant. The highest potassium uptake was recorded at 4 ml L^{-1} foliar spray followed by 3 ml L^{-1} foliar spray was at par treatment. The increased potassium uptake with nano urea can be attributed that it provides nitrogen in a slow-release form, reducing nitrogen losses and improving overall plant nutrient uptake efficiency (Ranjan *et al*., 2022) [16].

Interaction effect of levels of nitrogen and spray nano urea

The interaction effect of nitrogen levels and nano urea spray on potassium content in fodder was found to be non-significant. The interaction effect of nitrogen levels and nano urea (N × S) on potassium uptake was found to be statistically significant. This suggests that the combined effect of nitrogen fertilization and nano urea application influenced potassium uptake synergistically.

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