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Effect of Foliar Application of Nano Urea on Nutrient Content and Uptake by Pearl Millet (*Pennisetum glaucum* L.)

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***Abstract*— *Nitrogen is an indispensable component of proteins, nucleic acids, chlorophyll, phospholipids, vitamins, hormones and alkaloids, thereby playing a vital role throughout the plant life cycle, from vegetative growth to reproductive development. Foliar fertilization has emerged as an effective nutrient management strategy for improving nutrient use efficiency as compare to conventional methods. Nano urea offers several advantages over conventional urea, including greater solubility, enhanced stability, controlled nutrient release, targeted delivery, lower environmental toxicity and ease of application and handling. The present experiment was carried out during Kharif season of 2025 at the Crop Research Centre, Sardar Vallabhbhai Patel University of Agriculture and Technology, Meerut, Uttar Pradesh. The experiment was laid out in Randomized Block Design (RBD) with ten treatments and three replications to evaluate the effect of different schedules and concentrations of foliar-applied Nano Urea Plus in combination with recommended nitrogen doses on nutrient dynamics. The experimental soil was sandy loam, slightly alkaline, low in available nitrogen, medium in phosphorus and potassium. Among the treatments, T_{10} (40% RDN as basal + Nano urea plus @ 0.5% at PI and Booting stage + 35% RDN at Booting stage) proved superior by recording the highest nutrient content and uptake for pearl millet. Therefore, foliar application of nano urea, particularly T_{10}, can be recommended as sustainable nutrient management practice for enhancing nutrient content and uptake of pearl millet under semi-arid conditions.*

***Keywords*— Nano urea, RDN, pearl millet, nitrogen, phosphorus and potassium**

I. INTRODUCTION

Pearl millet (*Pennisetum glaucum* L.) is a major cereal crop cultivated extensively in the arid and semi-arid tropical regions of Asia and Africa, where it serves as a staple food for a large population (Ciampitti *et al*., 2024; Fatondji *et al*., 2024). As a C_4 crop, pearl millet possesses high photosynthetic efficiency and demonstrates remarkable tolerance to environmental stresses such as drought and high temperatures, making it well suited to rainfed and moisture-deficit conditions (Shrestha *et al*., 2023; Venkatesh *et al*., 2023). Nitrogen (N) is one of the most essential macronutrients required for plant growth and is the third most abundant element in plant dry matter after carbon and oxygen. It is an indispensable component of proteins, nucleic acids, chlorophyll, phospholipids, vitamins, hormones, and alkaloids, thereby playing a vital role throughout the plant life cycle, from vegetative growth to reproductive development (Chen *et al*., 2021; Jiang *et al*., 2024). To achieve higher crop productivity, substantial quantities of nitrogen fertilizers are commonly applied; however, plants utilize only about 30–50% of the applied nitrogen, resulting in poor nitrogen use efficiency (NUE) (Nacry *et al*., 2013).

Foliar fertilization has emerged as an effective nutrient management strategy for improving nutrient use efficiency by supplying nutrients directly through plant leaves. Compared with conventional soil application, foliar feeding facilitates rapid nutrient absorption and utilization, particularly under conditions where root uptake is limited (Fageria *et al*., 2009). Urea is one of the most commonly used nitrogen sources for foliar application because it readily supplies nitrogen to plants and enhances nutrient availability during critical growth stages (Khan *et al*., 2009). In recent years, nanotechnology has introduced a new generation of fertilizers in which nutrients are delivered as nanoparticles. Owing to their exceptionally high surface area-to-volume ratio, nano-sized particles dissolve more rapidly and promote efficient nutrient absorption by foliage (Abou El-Enin *et al*., 2023). Nano-fertilizers, generally ranging in size from 1 to 100 nm, have attracted considerable attention because they improve nutrient use efficiency while reducing nutrient losses (Kumar *et al*., 2023). Nano urea, containing 4% nitrogen, is one such innovation that offers several advantages over conventional urea, including greater solubility, enhanced stability, controlled nutrient release, targeted delivery, lower environmental toxicity, and ease of application and handling (Saudy *et al*., 2022). Nano urea is a nanotechnology-based liquid nitrogen fertilizer with particle sizes ranging from 20 to 50 nm, providing a substantially larger surface area than conventional urea granules and thereby improving nutrient absorption by plants (Raliya *et al*., 2018; Mahapatra *et al*., 2022).

II. MATERIAL AND METHOD

The field experiment was conducted during the *kharif* season of 2025 at the Crop Research Centre at Sardar Vallabhbhai Patel University of Agriculture and Technology in Meerut, (positioned at a latitude of 29° 08' North and longitude of 77° 40' East, with an elevation of 228 meters above sea level) located in western Uttar Pradesh, to study the effect of foliar application of nano urea on nutrient content and uptake by pearl millet (*pennisetum glaucum* l.)

The 10 treatments comprised of RDN and Nano urea plus fertilizer application were tested in randomized block design with three replications. The treatment details described in table.

Treatment details

Symbols	**Treatments**
T_1	Control
T_2	40% RDN as basal + Nano urea plus @ 0.3% at PI + 35% RDN at Booting stage
T_3	40% RDN as basal + Nano urea plus @ 0.3% at Booting stage + 35% RDN at PI
T_4	40% RDN as basal + Nano urea plus @ 0.3% at PI and Booting stage + 35% RDN at Booting stage
T_5	40% RDN as basal + Nano urea plus @ 0.4% at PI + 35% RDN at Booting stage
T_6	40% RDN as basal + Nano urea plus @ 0.4% at Booting stage + 35% RDN at PI
T_7	40% RDN as basal + Nano urea plus @ 0.4% at PI and Booting stage + 35% RDN at Booting stage
T_8	40% RDN as basal + Nano urea plus @ 0.5% at PI + 35% RDN at Booting stage
T_9	40% RDN as basal + Nano urea plus @ 0.5% at Booting stage + 35% RDN at PI
T_{10}	40% RDN as basal + Nano urea plus @ 0.5% at PI and Booting stage + 35% RDN at Booting stage

To evaluate nutrient content and uptake, representative plant samples (both seeds and stover) were collected from each plot at the time of harvest. The plant materials were gently washed with distilled water to remove dirt and oven-dried at 65°C until they reached a constant weight and then ground into a fine powder. The nitrogen content was determined by wet digestion of the plant sample with H_2SO_4 and H_2O_2 was estimated on a colorimeter after the development of colour with Nesseler's reagent (Snell and Snell, 1949). For phosphorus and potassium analysis, the ground samples were first broken down using a di-acid digestion method (Johnson and Ulrich, 1959). Following digestion, phosphorus levels were measured using the Vandomolybdo phosphoric acid yellow colour method, while potassium levels were recorded using a flame photometer (Jackson, 1973). Once the nutrient concentration (as a percentage) in the seeds and stover was found, the total nutrient uptake was calculated by multiplying those percentages by the crop's yield. This calculation was done using the following formula:

$$Uptake\ (kg\ ha^{-1}) = \frac{Nutrient\ content\ (\%) \times Yield\ (kg\ ha^{-1})}{100}$$

Total nutrient uptake (kg/ha) = Total nutrient uptake grain + total nutrient uptake by stover

III. RESULTS AND DISCUSSION

Nutrient content and their uptake

Nitrogen content in grain varied significantly among the treatments and ranged from 1.72 to 2.01 per cent. The highest nitrogen content (2.01%) was recorded under T_{10}, which was statistically at par with T_7 (1.95%), T_8 (1.93%), T_9 (1.92%), T_5 (1.90%) and T_6 (1.88%), but remained significantly superior to T_3 (1.84%), T_4 (1.82%), T_2 (1.79%) and the untreated control T_1 (1.72%). Treatments T_7, T_8, T_9, T_5 and T_6 were also statistically at par with one another. The lowest grain nitrogen content was recorded under the untreated control (T_1). Nitrogen content in stover ranged from 0.42 to 0.60 per cent and differed significantly among the treatments. The maximum nitrogen content (0.60%) was recorded under T_{10}, which was statistically at par with T_7 (0.57%), T_8 (0.56%), T_9 (0.55%), T_5 (0.55%) and T_6 (0.54%), but remained significantly superior to T_3 (0.51%), T_4 (0.50%), T_2 (0.48%) and T_1 (0.42%). Treatments T_7, T_8, T_9, T_5 and T_6 were statistically comparable with each other. The lowest stover nitrogen content was observed under the untreated control (T_1).

Phosphorus content in grain varied significantly among the treatments and ranged from 0.15 to 0.24 per cent. The highest phosphorus content (0.24%) was recorded under T_{10}, which was statistically at par with T_7 (0.23%), T_5 (0.22%), T_8 (0.22%), T_9 (0.22%) and T_6 (0.21%), but remained significantly superior to T_3 (0.20%), T_4 (0.19%), T_2 (0.18%) and the control T_1 (0.15%). Treatments T_7, T_5, T_8, T_9 and T_6 were also statistically at par with one another. The lowest phosphorus content in grain was recorded under the control (T_1). Phosphorus content in stover ranged from 0.10 to 0.18 per cent and differed significantly among the treatments. The maximum phosphorus content (0.18%) was recorded under T_{10}, which was statistically at par with T_7 (0.17%), T_5 (0.16%), T_8 (0.16%), T_9 (0.16%) and T_6 (0.15%), whereas it remained significantly superior to T_3 (0.14%), T_4 (0.14%), T_2 (0.13%) and T_1 (0.10%). Treatments T_7, T_5, T_8, T_9 and T_6 remained statistically comparable with each other. The lowest phosphorus content in stover was recorded under the control (T_1).

Potassium content in grain varied significantly among the treatments and ranged from 0.21 to 0.34 per cent. The highest potassium content (0.34%) was recorded under T_{10}, which was statistically at par with T_7 (0.32%), T_8 (0.31%), T_9 (0.31%), T_5 (0.30%) and T_6 (0.29%), but remained significantly superior to T_3 (0.27%), T_4 (0.26%), T_2 (0.25%) and the control T_1 (0.21%). Treatments T_7, T_8, T_9, T_5 and T_6 were also statistically at par with one another. The lowest potassium content in grain was recorded under the control (T_1). Potassium content in stover ranged from 1.48 to 1.76 per cent and differed significantly among the treatments. The highest potassium content (1.76%) was recorded under T_{10}, which was statistically at par with T_7 (1.72%), T_8 (1.70%), T_9 (1.69%), T_5 (1.68%) and T_6 (1.66%), whereas it remained significantly superior to T_3 (1.62%), T_4 (1.60%), T_2 (1.56%) and the control T_1 (1.48%). Treatments T_7, T_8, T_9, T_5 and T_6 remained statistically comparable with each other. The lowest potassium content in stover was recorded under the control (T_1).

Nitrogen uptake by grain was significantly influenced by the foliar application of nano urea and ranged from 27.96 to 41.92 kg ha^{-1}. The highest nitrogen uptake by grain (41.92 kg ha^{-1}) was recorded under T_{10}, which was statistically at par with T_7 (38.77 kg ha^{-1}), T_8 (37.93 kg ha^{-1}), T_9 (37.30 kg ha^{-1}) and T_5 (36.39 kg ha^{-1}), but remained significantly superior to T_6 (35.43 kg ha^{-1}), T_3 (33.36 kg ha^{-1}), T_4 (32.50 kg ha^{-1}), T_2 (31.29 kg ha^{-1}) and the untreated control T_1 (27.96 kg ha^{-1}). Treatments T_7, T_8, T_9, T_5 and T_6 also remained statistically at par with one another. Nitrogen uptake by stover varied significantly from 16.05 to 28.95 kg ha^{-1}. The highest nitrogen uptake by stover (28.95 kg ha^{-1}) was recorded under T_{10}, which was statistically at par with T_7 (26.56 kg ha^{-1}), T_8 (25.72 kg ha^{-1}), T_9 (24.90 kg ha^{-1}) and T_5 (24.64 kg ha^{-1}), whereas it remained significantly superior to T_6 (23.84 kg ha^{-1}), T_3 (21.21 kg ha^{-1}), T_4 (20.51 kg ha^{-1}), T_2 (19.27 kg ha^{-1}) and the untreated control T_1 (16.05 kg ha^{-1}). Treatments T_7, T_8, T_9, T_5 and T_6 were statistically at par among themselves. The lowest stover nitrogen uptake was recorded under the untreated control (T_1). Total nitrogen uptake ranged from 44.01 to 70.80 kg ha^{-1} and was significantly influenced by the treatments. The maximum total nitrogen uptake (70.80 kg ha^{-1}) was recorded under T_{10}, which was statistically at par with T_7 (65.33 kg ha^{-1}) and T_8 (63.65 kg ha^{-1}). The lowest total nitrogen uptake was recorded under the untreated control (T_1).

Phosphorus uptake by grain varied significantly from 2.44 to 5.01 kg ha^{-1}. The highest phosphorus uptake by grain (5.01 kg ha^{-1}) was recorded under T_{10}, which was statistically at par with T_7 (4.57 kg ha^{-1}), T_8 (4.32 kg ha^{-1}) and T_9 (4.27 kg ha^{-1}), but remained significantly superior to T_5 (4.21 kg ha^{-1}), T_6 (3.96 kg ha^{-1}), T_3 (3.63 kg ha^{-1}), T_4 (3.39 kg ha^{-1}), T_2 (3.15 kg ha^{-1}) and the control T_1 (2.44 kg ha^{-1}). Treatments T_7, T_8, T_9, T_5 and T_6 were statistically at par with one another. The lowest phosphorus uptake by grain was recorded under the control (T_1).

Phosphorus uptake by stover ranged from 3.82 to 8.69 kg ha^{-1} and was significantly influenced by the treatments. The highest phosphorus uptake by stover (8.69 kg ha^{-1}) was recorded under T_{10}, which was statistically at par with T_7 (7.92 kg ha^{-1}) and T_8 (7.35 kg ha^{-1}), but remained significantly superior to T_9 (7.24 kg ha^{-1}), T_5 (7.17 kg ha^{-1}), T_6 (6.62 kg ha^{-1}), T_3 (5.82 kg ha^{-1}), T_4 (5.74 kg ha^{-1}), T_2 (5.22 kg ha^{-1}) and the control T_1 (3.82 kg ha^{-1}). Treatments T_7, T_8, T_9, T_5 and T_6 also remained statistically at par with one another. The lowest phosphorus uptake by stover was recorded under the control (T_1). Total phosphorus uptake varied significantly among the treatments and ranged from 6.26 to 13.70 kg ha^{-1}. The maximum total phosphorus uptake (13.70 kg ha^{-1}) was recorded under T_{10} and lowest total phosphorus uptake was recorded under the control (T_1).

Potassium uptake by grain varied significantly from 3.41 to 7.09 kg ha^{-1}. The highest potassium uptake by grain (7.09 kg ha^{-1}) was recorded under T_{10}, which was statistically at par with T_7 (6.36 kg ha^{-1}) and T_8 (6.09 kg ha^{-1}), but remained significantly superior to T_9 (6.02 kg ha^{-1}), T_5 (5.75 kg ha^{-1}), T_6 (5.47 kg ha^{-1}), T_3 (4.89 kg ha^{-1}), T_4 (4.64 kg ha^{-1}), T_2 (4.37 kg ha^{-1}) and the control T_1 (3.41 kg ha^{-1}). Treatments T_7, T_8, T_9, T_5 and T_6 were statistically at par with one another. The lowest potassium uptake by grain was recorded under the control (T_1). Potassium uptake by stover ranged from 56.55 to 84.93 kg ha^{-1} and was significantly influenced by the treatments. The highest potassium uptake by straw (84.93 kg ha^{-1}) was recorded under T_{10}, which was statistically at par with T_7 (80.13 kg ha^{-1}) and T_8 (78.08 kg ha^{-1}), but remained significantly superior to T_9 (76.48 kg ha^{-1}), T_5 (75.27 kg ha^{-1}), T_6 (73.30 kg ha^{-1}), T_3 (67.37 kg ha^{-1}), T_4 (65.64 kg ha^{-1}), T_2 (62.64 kg ha^{-1}) and the control T_1 (56.55 kg ha^{-1}). Treatments T_7, T_8, T_9, T_5 and T_6 remained statistically at par with one another. The lowest potassium uptake by stover was recorded under the control (T_1). Total potassium uptake varied significantly among the treatments and ranged from 59.96 to 92.02 kg ha^{-1}. The maximum total potassium uptake (92.02 kg ha^{-1}) was recorded under T_{10}, which was statistically at par with T_7 (86.49 kg ha^{-1}), but remained significantly superior to T_8 (84.17 kg ha^{-1}), T_9 (82.50 kg ha^{-1}), T_5 (81.02 kg ha^{-1}), T_6 (78.77 kg ha^{-1}), T_3 (72.26 kg ha^{-1}), T_4 (70.28 kg ha^{-1}), T_2 (67.01 kg ha^{-1}) and the control T_1 (59.96 kg ha^{-1}). Treatments T_7, T_8, T_9, T_5 and T_6 were statistically at par with one another. The lowest total potassium uptake was recorded under the control (T_1).

The improvement in nutrient content following foliar application of nano urea may be attributed to enhanced nitrogen availability and improved physiological activity throughout the crop growth period. Nitrogen is the principal constituent of amino acids, proteins, enzymes and chlorophyll molecules and therefore regulates numerous metabolic processes associated with nutrient absorption, assimilation and translocation (**Sandhu *et al.*, 2021**). The higher phosphorus and potassium contents and uptake recorded under nano urea treatments may be explained by the synergistic interaction between nitrogen and other essential nutrients. Nitrogen-induced enhancement in root exudation and microbial activity also increases phosphorus solubilization and nutrient availability in the rhizosphere (**Wang *et al.*, 2023**). Improved photosynthetic activity and carbohydrate production further enhance root energy status, facilitating active uptake and translocation of phosphorus and potassium to developing plant tissues (**Khan *et al.*, 2023**).

Table 1: Effect of foliar application of nano urea on N, P and K content (%) of pearl millet

Treatments	Nitrogen content		Phosphorus content		Potassium content	
	Grain	Stover	Grain	Stover	Grain	Stover
T_1	1.72	0.42	0.15	0.10	0.21	1.48
T_2	1.79	0.48	0.18	0.13	0.25	1.56
T_3	1.84	0.51	0.20	0.14	0.27	1.62
T_4	1.82	0.50	0.19	0.14	0.26	1.60
T_5	1.90	0.55	0.22	0.16	0.30	1.68
T_6	1.88	0.54	0.21	0.15	0.29	1.66
T_7	1.95	0.57	0.23	0.17	0.32	1.72
T_8	1.93	0.56	0.22	0.16	0.31	1.70
T_9	1.92	0.55	0.22	0.16	0.31	1.69
T_{10}	2.01	0.60	0.24	0.18	0.34	1.76
S Em (±)	0.02	0.02	0.01	0.01	0.02	0.02
CD at 5%	0.05	0.04	0.03	0.03	0.04	0.05

Table 2: Effect of foliar application of nano urea on N, P and K uptake (Kg ha^{-1}) of pearl millet

Treatments	Nitrogen uptake			Phosphorus uptake			Potassium uptake		
	Grain	Stover	Total	Grain	Stover	Total	Grain	Stover	Total
T_1	27.96	16.05	44.01	2.44	3.82	6.26	3.41	56.55	59.96
T_2	31.29	19.27	50.56	3.15	5.22	8.37	4.37	62.64	67.01
T_3	33.36	21.21	54.57	3.63	5.82	9.45	4.89	67.37	72.26
T_4	32.50	20.51	53.01	3.39	5.74	9.13	4.64	65.64	70.28
T_5	36.39	24.64	61.03	4.21	7.17	11.38	5.75	75.27	81.02
T_6	35.43	23.84	59.27	3.96	6.62	10.58	5.47	73.30	78.77
T_7	38.77	26.56	65.33	4.57	7.92	12.49	6.36	80.13	86.49
T_8	37.93	25.72	63.65	4.32	7.35	11.67	6.09	78.08	84.17
T_9	37.30	24.90	62.20	4.27	7.24	11.51	6.02	76.48	82.50
T_{10}	41.92	28.95	70.80	5.01	8.69	13.70	7.09	84.93	92.02
S Em (±)	0.74	1.49	2.87	2.44	3.82	6.26	0.32	2.75	2.99
CD at 5%	1.59	3.19	6.16	3.15	5.22	8.37	0.68	5.89	6.40

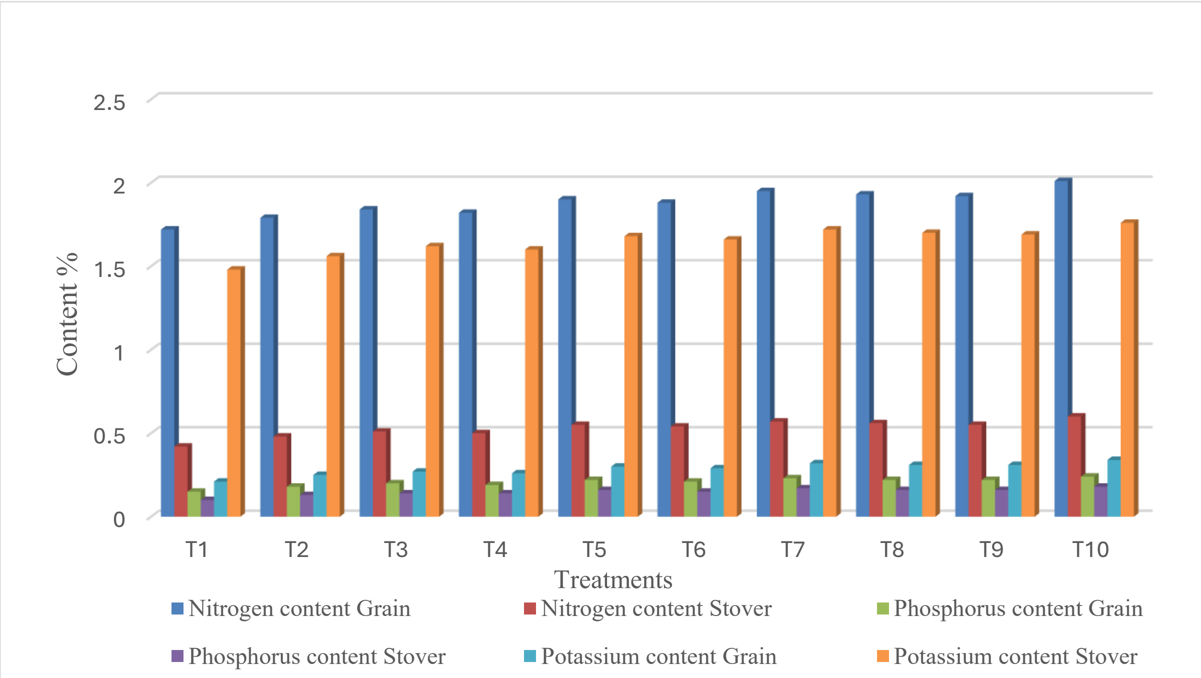

Fig. 1: Effect of foliar application of nano urea on N, P and K content (%) of pearl millet

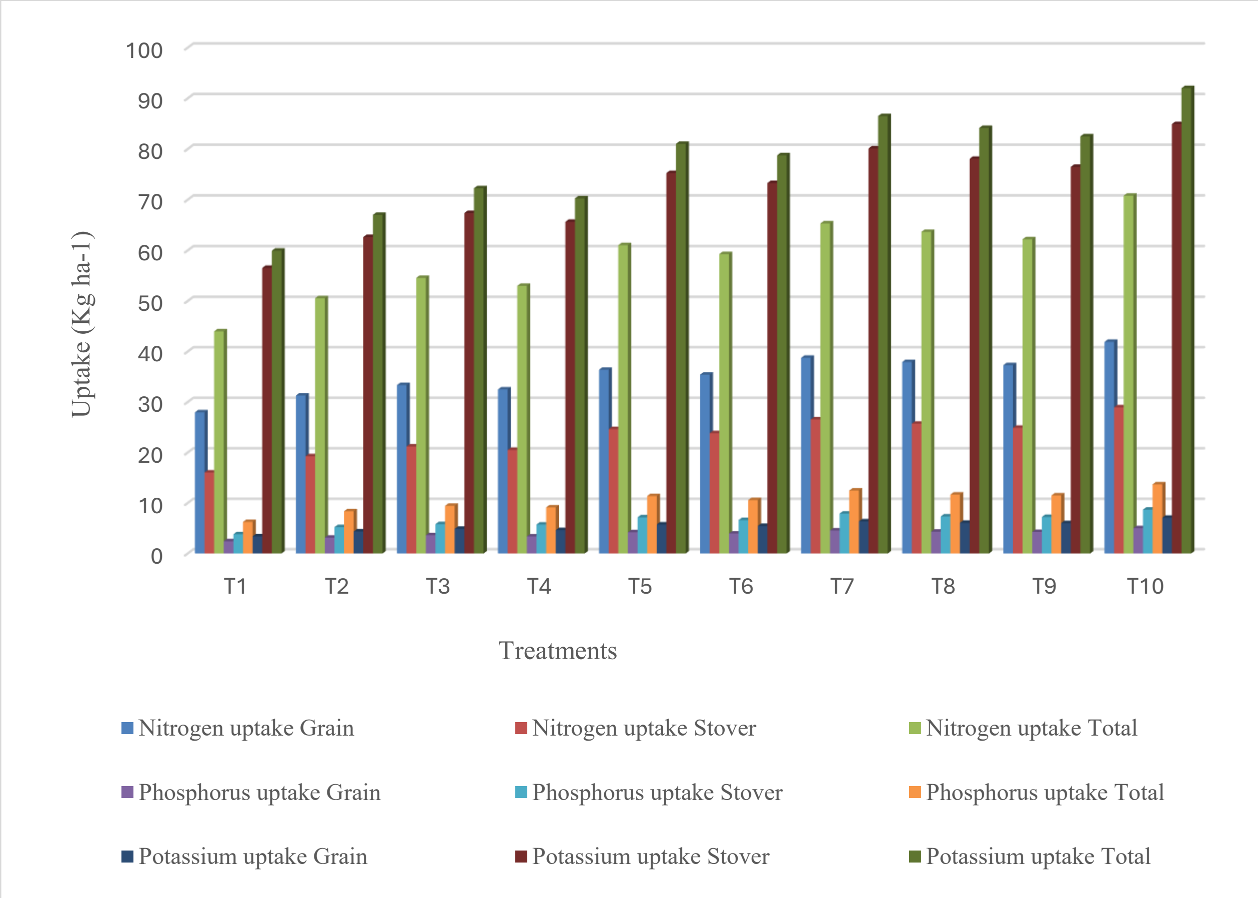

Fig. 2: Effect of foliar application of nano urea on N, P and K uptake (Kg ha^{-1}) of pearl millet

IV. CONCLUSION

From the experiment result, it was concluded that the highest nutrient content and uptake was found under treatments, T_{10} (40% RDN as basal + Nano urea plus @ 0.5% at PI and Booting stage + 35% RDN at Booting stage) proved to be the most effective.

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