FERTILIZER NOVELTY: INVESTIGATING THE ROLE OF DIFFERENT UREA TYPES IN MINIMIZING LEACHING LOSS TO MAXIMIZING ITS USE EFFICIENCY

ABSTRACT

The laboratory study was conducted to understand the fate of N using different types of urea fertilizers in *Alfisol*. The leaching study indicated a lower amount of NH_4^+-N in the leachate was removed in CSPC @3% and neem-coated urea as compared to conventional urea and prilled urea. In CSPC @3% recorded 55.00 and 110.00 µg at the 0th and 25th day of leachate collection (DLC) and thereafter decreased to 54.00 µg at the 50th DLC, however, the amount was higher than other treatments indicating its slow-release pattern. The NO_3^- -N in leachate was lowest in the same treatment (CSPC @3%) which recorded 17.71 to 57.00 µg at 0-25th DLC and decreased to 31.00 µg at 50th DLC. Through this, it is proved that when uncoated urea is applied, hydrolysis of urea takes place at field capacity due to which it converts into different forms like available, ammonical, and nitrate. Although available nitrogen is present in larger quantities than ammonical and nitrate. Nitrate form was present in the least quantity as its losses due to leaching. Therefore, to minimize such losses coated urea like CSPC @3% and NCU should be used to increase nitrogen use efficiency.

Key words: Corn starch based superabsorbent coated @3% prilled urea (CSP @3%), neem coated urea, leaching, NUE (Nitrogen Use efficiency)

1 INTRODUCTION

Nitrogen is widely regarded as the "king" among essential plant nutrients due to its pivotal role in various biological processes. It is a fundamental component of chlorophyll, amino acids, proteins, and enzymes, all crucial for plant growth and development. Despite being abundant in the atmosphere, plants cannot directly utilize atmospheric nitrogen (N_2) due to its triple bond nature. Instead, they rely on nitrogen in the form of nitrate (NO_3^-) or ammonium (NH_4^+) for nourishment, with most plants absorbing nitrogen in the NO_3^- form, except for rice, which prefers NH_4^+ (Thind, *et al.* 2010).

In agricultural soils, nitrogen availability varies but generally falls within the range of 0.02% to 0.4% on a weight basis. Indian soils, in particular, tend to be low in available nitrogen due to factors such as poor organic matter content and high temperatures. To compensate for this deficiency and prevent nitrogen loss from soils, external nitrogen sources, such as fertilizers, are crucial for crop production.

Urea fertilizer holds a prominent position in the global nitrogen fertilizer market due to its cost-effectiveness, high nitrogen content (46%), and ease of production, transport, and storage. In India, urea accounts for a significant portion of nitrogen fertilizer consumption. However, the efficiency of conventional urea fertilizers is often compromised by factors such as ammonia volatilization, denitrification, leaching, and immobilization, leading to low nitrogen use efficiency (NUE), typically ranging from 30 to 35 per cent (Galloway and Cowling, 2002; Ladha *et al*., 2005).

To address these challenges and improve NUE, various technologies have been developed, including controlled-release urea (CRU) fertilizers (Dong *et al*., 2016). CRU fertilizers release nitrogen gradually over time, mimicking organic nitrogen sources and reducing the risk of nitrogen loss (Ali *et al* 2020). Coating urea with materials like neem oil or biodegradable polymers has shown promise in enhancing NUE by regulating nitrogen release and minimizing losses (Prasad, 2005; Prasad *et al*., 2007; Sivasakthy and Gnanavelrajah, 2012).

Among biodegradable polymers, starch-based superabsorbents have gained attention for their environmentally friendly properties (Farmaha and Sims, 2013). Starch, derived from sources such as cereal grains and tubers, can effectively reduce leaching loss of nitrogen when used as a coating material for urea fertilizers (Liu *et al*. 2017). Research into other naturally available, cost-effective coating materials continues (Prasad, 2005), aiming to further improve NUE and mitigate environmental impacts associated with nitrogen fertilization (Bello-perez *et al*., 1998). Nitrogen management in agriculture is crucial for sustainable productivity and environmental conservation. Innovations in urea fertilizer technology, such as controlled-release formulations and biodegradable coatings, offer promising solutions to enhance nitrogen use efficiency and minimize nitrogen losses, contributing to resilient and sustainable agricultural systems.

2 MATERIAL AND METHODS

2.1 Soil collection and processing

The experimental soil belonging to Order: Alfisol was collected from a field situated College of Agriculture, V. C. farm, Mandya. (at ---12˚34″ N, 76˚49″ E, and 713 m above mean sea level) located under the Southern Dry Zone (Zone-6) of Karnataka. The bulk soil samples were collected from the upper 15 cm of surface soil. While collection all the stubbles, gravels, and stones were removed, shade dried, and passed through a 2 mm size sieve. The important initial soil properties were analyzed following the standard analytical methods and listed in Table. 1.

Table 1: Initial soil Physio-chemical parameters

Parameters		Values
Physical properties		
Particle size distribution	Sand (%)	74.52
	Silt (%)	12.5
	Clay (%)	12.98
	Textural class	Sandy loam
Maximum water holding capacity (%)		52.5
Field capacity (%)		26.25
Bulk Density (g cm^{-1})		1.49
Particle Density (g cm^{-1})		2.51
Chemical properties		
pH (1:2.5)		8.12
EC (dSm^{-1})		0.27
OC (g kg^{-1})		6.92
Available Nitrogen (kg ha^{-1})		250.88
Available Phosphorus (kg ha^{-1})		194.37
Available Potassium (kg ha^{-1})		365.16
Exchangeable Calcium [c mol (p+) kg^{-1}]		10.10
Exchangeable Magnesium [c mol (p+) kg^{-1}]		4.4
Available Sulphur (mg kg^{-1})		25.12
DTPA-Iron (mg kg^{-1})		9.16
DTPA-Copper (mg kg^{-1})		1.21
DTPA-Manganese (mg kg^{-1})		5.87
DTPA-Zinc (mg kg^{-1})		2.89

2.2 Experimental setup

Experiment on leaching loss of N from various N sources that applied to soil was conducted under greenhouse condition. Known amount of similar size pots were cleaned and a hole was made just contiguous to bottom surface. A tube having 1.50 cm diameter was tightly fixed to the hole using L-bow joint with rubber case to enable leachate collection without leakage. To each pot air dried and sieved soil was added with maintaining bulk density.

Plate 1: Different types of urea fertilizers

2.3 Imposition of leaching

The *Alfisol* soil (10 kg) filled in the pot was brought to maximum water holding capacity by impounding the calculated quantity of water. The frustum volume of the pot was used to calculate the required amount of irrigation water as follows

$$V= \frac{1}{3} \Pi h (r^2 + R^2 + Rr)$$

Where, V= Volume of frustum (volume of irrigation water), h= height (5 cm), R= upper radius and r = lower radius

Initially, 2625 mL of water was added to bring potted soil to its MWHC. The leachate was collected at 5-day intervals (starting from the 0th day to till 45th day) and an extra 200 mL of water was added each time to collect leachate in a clean plastic jar. However, during lingering days soil moisture was maintained at FC, which was done by adding water based on weight loss in every 24 hrs.

2.4 Determination of ammonia (NH_4^+) and nitrate (NO_3^-)

Five milliliters of leachate were distilled with 25 mL of 40 percent NaOH in the Kjeldhal N analyzing instrument. The ammonia released was trapped in 4 percent boric acid containing mixed indicator titrated against 0.05N standard sulphuric acid and expressed as NH_4^+-N (Subbiah and Asija, 1956). Subsequently, for the same sample contained in a distillation tube 0.50 g of Devarda's alloy was added and repeated the above procedure to get NO_3^- -N (Richard, 1968).

2.5 Statistical analysis

The data about leaching losses of N had been instructed to statistical analysis adopting completely randomized block design (CRD) Gomez and Gomez (1984). One-way analysis of variance (ANOVA) was done using statistical package SPSS version 9.1.6.3. Further, the significant difference between treatment means was compared with critical differences at a 5% confidence level.

3 Results and Discussion

3.1 Ammonical N content of leachate collected after successive leaching of soil

Variations in the ammonical N content of leachate during leaching of soil applied with different urea fertilizers are given in Table 2.

Changes in ammonical N content on the day of leaching (0th day) among the treatments were non-significant. Initially (5th DLC), NH_4^+ -N content in the leachate was significantly higher in treatment T2 (84.73 µg) that received CU followed by T3 (75.94 µg) received PU and T8 (74.14 µg) that applied with PCSA @3%. Although treatment T8 (PCSA @3%) and T9 (PCSA @6%) were found to be on par with each other (74.14 µg in both treatments). Further, the significantly lowest value of NH_4^+ -N was recorded in the control (41.00 µg) followed by T6 received CSPC @3%.

Subsequently, the NH_4^+ -N content of leachate decreased with increasing days in treatments T1, T2, T3, T8 and T9. Whereas, treatments T4 and T6 have shown increasing to till 25th day of leachate collection. Further, irrespective of treatment plummet of NH_4^+ -N content was noticed. However, at the 50th DLC, the maximum NH_4^+ -N content was recorded in CSPC @3% (59.00 µg) which was on par with NCU (54.00 µg). Further, the least NH_4^+ -N content was noticed in the control (9.00 µg) followed by CU (12.00 µg).

Under the controlled condition, the highest concentration of NH_4^+ -N in CU was recorded on day 7, indicating that virtually all the urea was hydrolyzed within ten days (Paramasivam and Alva, 1997). Due to the uncoating CU and PU when came in contact with water and urease Enzyme, it was activated and complete hydrolysis occurred and liberated as free ammonia at a faster rate. Whereas in coated urea (neem

Table 2: Effect of different types of urea fertilizers on NH_4^+ -N content of leachate collected from soil after successive leaching

Treatments	NH_4^+ -N (µg)										
	0^{th}	**5^{th}**	**10^{th}**	**15^{th}**	**20^{th}**	**25^{th}**	**30^{th}**	**35^{th}**	**40^{th}**	**45^{th}**	**50^{th}**
	DLC										
T_1: Control	9.87	41.00	55.00	52.87	40.56	30.00	27.00	20.00	16.00	13.00	9.00
T_2: Urea(uncoated)	12.00	84.73	90.00	60.00	48.00	39.00	35.00	28.00	25.00	21.00	12.00
T_3: Prilled urea (uncoated)	12.00	75.94	83.00	67.00	58.00	47.00	44.49	36.00	33.00	29.00	18.15
T_4: Neem coated urea	11.00	60.00	72.25	83.00	85.00	99.00	96.00	92.65	75.00	57.00	54.00
T_5: Neem coated prilled urea	11.00	68.00	79.12	78.00	76.00	75.00	70.27	64.00	50.00	42.00	33.00
T_6: Corn starch based superabsorbent coated (@3%) prilled urea	11.00	55.00	69.00	89.00	96.00	110.00	106.00	99.00	85.00	68.00	59.00
T_7: Corn starch based superabsorbent coated (@6%) prilled urea	11.00	70.00	80.73	75.00	73.00	74.00	66.86	63.00	49.00	39.00	32.00
T_8: Physical blending of prilled urea + corn starch superabsorbent (13.44 kg ha^{-1})	12.00	74.14	82.00	69.00	63.65	55.78	51.60	46.84	42.00	32.00	25.00
T_9: Physical blending of prilled urea + corn starch superabsorbent (27.17 kg ha^{-1})	12.00	74.14	84.00	68.00	62.00	53.00	49.00	42.00	38.00	30.00	20.00
S. Em. ±	**0.41**	**1.92**	**1.54**	**1.40**	**1.60**	**1.57**	**2.00**	**1.89**	**1.76**	**1.40**	**1.21**
CD @ 1%	**NS**	**7.80**	**7.68**	**6.98**	**8.02**	**7.84**	**8.12**	**7.71**	**7.16**	**5.72**	**4.94**

Note: Leachate was collected at 5 days interval

coated and corn starch-based superabsorbent) due to the coated layer which acts as a semipermeable membrane. With the influence of soil temperature, moisture penetrates inside through that membrane and dissolves the nutrient core which builds up the osmotic pressure inside the coated granule. They can reduce N losses due to their potential to delay N release patterns (Jadon *et al*., 2018).

The decrease in leaching of NH_4^+ -N could be due to loss of NH_3 by volatilization or transformation of NH_4^+ -N to NO_3^- -N by nitrification. Along with this NH_4^+ ions are positively charged they may get absorbed by negatively charged soil particles. These results are in confirmatory with Mohanty *et al*. (2021), Abbasi *et al*., (2011) also reported that application of neem coated urea delayed the NH_4^+ reduction.

3.2 Nitrate N content of leachate collected after successive leaching of soil

The leaching of NO_3^- -N followed a similar trend as that of NH_4^+ (table 2). There was no significant difference among treatments on the initial day. Application of different urea fertilizers showed a significant loss of NO_3^- -N content after the 5th day of leaching fractionation.

Sparingly, higher NO_3^- -N content was observed in CU *i.e*., T2 (33.00 µg) which increased up to the 30th day (77.00 µg) and reduced in successive days and had less concentration at the last leachate (56.00 µg). The same trend was followed by T3, T9, and T8 where the concentration increased from 30.00 to 74.00, 28.00 to 72.00, and 28.00 to 70.00 µg up to the 30th day of leachate fractionation after that it reduced to 52.00, 51.00 and 49.00µg, respectively. It was interesting to note a lesser amount of NO_3^- -N initially in coated urea fertilizer (neem coated and corn starch based superabsorbent) but the concentration steadily increased up to the collection of 5th leachate (30th DLC) and it showed a decrease in concentration till to the end. However, in NCU NO_3^- -N content increased from 23.00 to 59.00 µg and decreased to 33.00 µg. Whereas, in CSPC @3% NO_3^- -N content increased from 22.00 to 57.00 µg and was reduced to 31.00 µg in the last leachate collection (50th day).

The higher content of NO_3^- -N in conventional and prilled urea may be due to the rapid rate of urea hydrolysis and nitrification rate which causes faster conversation of NH_4^+ to NO_3^- which resulted in maximum leaching in the form NO_3^- (99 %) compared with NH_4^+ (Paramasivam and Alva, 1997). Further, this may be due to repulsion between negatively charged nitrate ions and negatively charged soil particles.

A lesser NO_3^- -N concentration in the leachate from the coated urea fertilizer (CSPC @3% and NCU) of the leaching study suggests that a somewhat longer period is needed for the release of urea from the coating. In the case of neem-coated urea, the alkaloid present in the neem oil might have inhibited the urease-producing microbial activities (Jadon *et al*. 2018). The corn starch-based superabsorbent was coated with a material that has the property of water retaining, they can retain large quantities of water and nutrients. The stored water and nutrients are released slowly. This results in slow release in the amount of NO_3^- -N was noticed in leachate. These results are corroborated with Islam *et al*. (2011).

3.3 Soluble cations in leachate collected after successive leaching

The interesting fact is that the soil used for the experiment has a relatively high content of available Ca^{2+}, Mg^{2+}, K^+, and Na^+ ions. Nitrate leaching can deplete the soil exchangeable cations such as Ca^{2+}, Mg^{2+}, and K^+ which might have increased soil acidity. Anyhow among the cations maximum quantity of leaching occurs in Ca^{2+} followed by Mg^{2+}. As soil is light textured (sandy loam) indicating greater loss of Ca^{2+}.

The higher Ca^{2+} and Mg^{2+} concertation, in the beginning, indicated high exchangeable Ca^{2+} forms were transformed into soluble. After this stage, the Ca^{2+} and Mg^{2+} concentrations continued to decline slowly until the end of the leaching period. In addition, Ca^{2+} and Mg^{2+} content in the leachate of all the treatments was higher than control, which may imply that urea fertilizer contributed to the release of soluble Ca^{2+} and Mg^{2+}. However, there was no difference in Ca^{2+} and Mg^{2+} leached between the treatments that received different urea fertilizers. However, after the 35th day, the significance regarding Ca^{2+} and Mg^{2+} was noticed because of the decrease in pH which most efficiently affected the replacement of bonded Ca^{2+} and Mg^{2+} in the soil solution. However, the higher content in coated urea is mainly due to the NO_3^- -N release pattern of coated urea (Mohanty *et al*. 2021).

Table 3: Effect of different types of urea fertilizers on NO_3^--N content of leachate collected from soil after successive leaching

Treatments	NO_3^--N (µg)										
	0th	**5th**	**10th**	**15th**	**20th**	**25th**	**30th**	**35th**	**40th**	**45th**	**50th**
	DLC										
T_1: Control	16.39	18.60	27.00	39.00	48.00	43.00	29.00	23.00	16.00	14.00	12.00
T_2: Urea(uncoated)	18.00	33.00	43.00	58.58	68.76	72.00	77.00	75.62	69.00	63.00	56.00
T_3: Prilled urea (uncoated)	18.00	30.00	40.00	53.46	64.13	69.00	74.00	69.00	64.54	58.00	52.00
T_4: Neem coated urea	17.45	23.00	32.00	45.00	53.49	57.00	59.00	51.00	44.00	37.00	33.00
T_5: Neem coated prilled urea	19.00	25.00	35.00	47.00	57.00	61.07	62.00	56.00	49.00	42.00	39.00
T_6: Corn starch based superabsorbent coated (@3%) prilled urea	17.71	22.00	31.00	43.00	51.00	55.00	57.00	49.00	41.00	36.00	31.00
T_7: Corn starch based superabsorbent coated (@6%) prilled urea	18.00	26.00	36.00	49.00	58.00	62.00	64.00	56.00	50.00	45.00	42.00
T_8: Physical blending of prilled urea + corn starch superabsorbent (13.44 kg ha^{-1})	18.58	28.00	39.00	52.00	62.00	66.00	70.00	65.00	61.00	54.00	49.00
T_9: Physical blending of prilled urea + corn starch superabsorbent (27.17 kg ha^{-1})	18.22	28.00	40.00	53.00	63.27	68.00	72.00	67.00	62.65	56.00	51.00
S. Em. ±	**0.50**	**0.61**	**0.58**	**0.57**	**0.81**	**0.80**	**0.59**	**1.11**	**1.67**	**0.99**	**0.94**
CD @ 1%	**NS**	**2.98**	**2.92**	**2.84**	**3.98**	**4.01**	**2.96**	**5.58**	**5.84**	**4.97**	**4.72**

Note: Leachate was collected at 5 days interval

The hydron ions produced during nitrification can release Ca^{2+} and Mg^{2+} by exchange from soil colloids, resulting in a high amount of Ca^{2+} and Mg^{2+} leaching from coated urea at the end. Initial higher K^+ concentration in the leachates was due to preliminary treatment of the saturated soils with deionized water which attended there was no significant difference. The release of K^+ and Na^+ is a slow process indicating a decrease in the concentration of K^+ and Na^+ in leachate (Liu *et al.*, 2017).

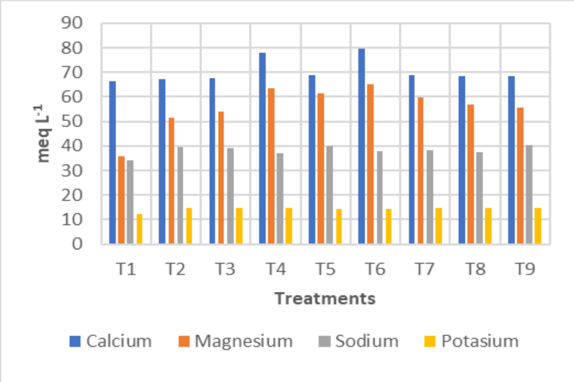

Fig 1. Cumulative amount of cations in leachate collected after ten successive leaching from soil

NH_4^+ and K^+ compete for the same binding sites on the clay colloids which revealed lower fixation of K^+ found with an increased in NH_4^+ content in soil which may get bonded with soil colloids or may converted to the NO_3^--N. As in uncoated urea, the NH_4^+ was leached in a higher amount initially indicating lesser replacement of K^+ which increases concentration in leachate. But in coated urea due to the behavior of slow releasing initially, the K^+ was leached with water as potassium held by soil colloids which was easily displaced. Further, lower in K^+ content at the end may be due to the complete leaching of water-soluble and exchangeable K^+. Similar results are reported by Mohamed *et al*. (2020).

3.4 Soluble anions in leachate collected after successive leaching

The chloride ion content in the leachate initially peaked but gradually declined with successive leaching, showing variations among treatments after the 10th day. Initially, higher chloride levels were noted in treatments T6 (CSPC @3%) and T4 (NCU), while uncoated urea treatments (CU and PU) exhibited the lowest chloride content. Chloride in soil primarily exists in soluble form and moves readily into the soil solution, resulting in higher concentrations in leachate, especially in sandy loam soil with high hydraulic conductivity. Total carbonate content initially showed no significant differences among treatments but varied notably after the 10th day of leachate collection. Initially higher levels were observed in treatments T2 (CU) and T3 (PU), with decreasing trends over time. Treatments with coated urea formulations showed lower initial total carbonate content but maintained higher levels compared to uncoated urea treatments throughout the leaching experiment. Sulfate content in the leachate was initially higher and decreased steadily over time. Treatments with coated urea formulations exhibited higher initial sulfate levels compared to uncoated urea treatments, with concentrations decreasing over successive leaching events. Sulfate sulfur is prone to rapid leaching losses from the soil, especially in the presence of monovalent cations, leading to higher concentrations in the soil solution and subsequent leachate. Urea application enhances sulfate concentration in the soil solution, contributing to its increased leaching.

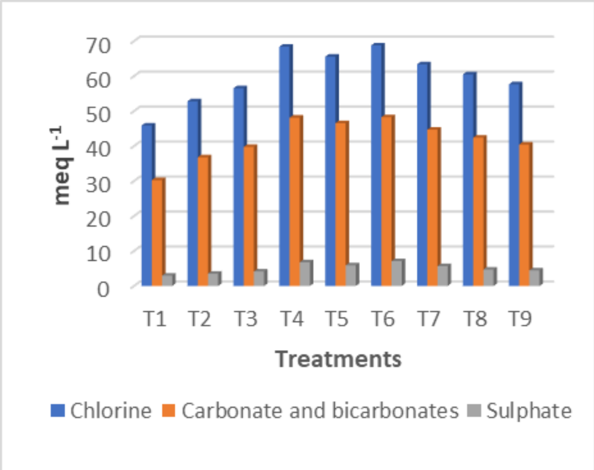

Fig 2. Cumulative amount of anions in leachate collected after ten successive leaching from soil

4 CONCLUSION:

Nitrogen is indispensable for plant growth and development, playing a vital role in various biological processes. Despite its abundance in the atmosphere, plants require nitrogen in forms such as nitrate and ammonium, which are not readily available from the air. Agricultural soils often lack sufficient nitrogen levels, necessitating the use of external nitrogen sources like fertilizers to sustain crop productivity. Urea fertilizer, with its high nitrogen content and cost-effectiveness, is extensively used in agriculture globally. However, conventional urea fertilizers suffer from drawbacks such as nitrogen losses through volatilization, leaching, and denitrification, leading to low nitrogen use efficiency. To address these challenges, controlled-release urea (CRU) fertilizers have been developed, including those with biodegradable coatings like starch-based superabsorbents. In this study, we investigated the leaching losses of nitrogen from various urea fertilizers applied to soil under greenhouse conditions. The experiment revealed significant differences in ammonium and nitrate leaching among different urea formulations. Uncoated urea fertilizers exhibited higher initial leachate nitrogen content compared to coated urea formulations, indicating a faster release of nitrogen from uncoated urea. However, coated urea formulations demonstrated a delayed release pattern, resulting in lower nitrogen leaching over time. Furthermore, the study assessed the leaching of soluble cations and anions, revealing variations in chloride, total carbonates, and sulphate concentrations in the leachate among different treatments. Coated urea formulations exhibited higher initial levels of total carbonates and sulphates compared to uncoated urea, suggesting a slower release of these compounds from coated urea granules. Overall, the findings highlight the potential of coated urea fertilizers, particularly those incorporating starch-based superabsorbents, to mitigate nitrogen losses through leaching and improve nitrogen use efficiency in agricultural soils. These innovations in urea fertilizer technology hold promise for enhancing sustainable agricultural practices, reducing environmental impacts, and ensuring food security in the face of increasing global nitrogen demand. Further research and field trials are warranted to validate these findings and optimize coated urea formulations for widespread adoption in agriculture.

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