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Assessing the Impact of Coated and Prilled Urea Fertilizers on Nitrogen Dynamics and Fodder Maize Yield in *Alfisols*

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The study investigates the impact of different urea fertilizers on nitrogen mineralization, leaching losses, and growth, yield of fodder maize in Alfisols. Nitrogen is vital for plant growth but deficient in soils. Urea, a widespread nitrogen fertilizer, suffers from significant losses, prompting the development of controlled-release urea (CRU) fertilizers. This study assesses various urea formulations with coated urea and prilled urea. Laboratory incubation studies show that coated urea

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exhibits slower NH_4^+-N release, reducing losses and improving efficiency compared to uncoated urea. Nitrate content increases steadily periodically with coated urea, potentially enhancing nitrogen availability to plants. Greenhouse experiments reveal significant differences in plant height, leaf number, and leaf area among treatments. Coated urea formulations, chiefly CSPC @3%, demonstrate superior growth parameters (plant height-169.56cm, number of leaves-10.33 and leaf area-1850.59), yield (green fodder-328.25 gplant^{-1}, dry fodder-198.61 gplant^{-1} and dry matter percentage-54.52) and quality parameters (crude protein-4.03, total ash content-3.82%) compared to prilled urea growth parameters (plant height-113.38cm, number of leaves-8.07 and leaf area-1670.98), yield (green fodder-246.26 gplant^{-1}, dry fodder-116.35 gplant^{-1} and dry matter percentage-44.32) and quality parameters (crude protein-2.88, total ash content-2.75%), likely due to sustained nitrogen release. Higher nitrogen availability from coated urea leads to increased forage yield and quality. The findings suggest that coated urea fertilizers, specially CSPC @3% advocate improved nitrogen management, enhancing fodder maize productivity and sustainability.

Keywords: Mineralization; coated urea; controlled release urea; Alfisols.

1. INTRODUCTION

Alfisols constitute a significant soil order within the Karnataka region, characterized by their enrichment in aluminum (Al) and iron (Fe). These soils possess distinct features including light coloration, clay enrichment, and high exchangeable cations, with a base saturation exceeding 35 per cent. Their favorable texture, coupled with their presence in semi-arid to humid regions, renders *Alfisols* naturally fertile, thus playing a crucial role in food and fiber production. Despite their nutrient-rich profile, *Alfisols* often exhibit deficiencies in organic matter, nitrogen, phosphorus, sulfur, and zinc, which necessitates the use of organic fertilizers and supplements for sustainable soil health and productivity [1].

Among essential plant nutrients, nitrogen holds paramount importance, being referred to as the "King of plant essential nutrients." It serves as a vital component of chlorophyll, amino acids, proteins, and enzymes, and is required by plants in substantial quantities, surpassing other essential nutrients. However, despite the abundance of nitrogen in the atmosphere, plants cannot directly utilize atmospheric nitrogen due to its molecular form (N2) characterized by a triple bond (N≡N). Consequently, soils typically contain nitrogen in limited available forms, often insufficient for optimal plant growth, particularly in regions with poor organic matter content and high temperatures, such as Indian soils [2].

To address the deficiency in available nitrogen, various nitrogenous fertilizers are utilized, with urea occupying a prominent position in the global nitrogen fertilizer market due to its cost-effectiveness and high nitrogen content. However, conventional urea application methods often result in significant nitrogen losses through processes such as ammonia volatilization, denitrification, leaching, and immobilization, thereby reducing fertilizer nitrogen-use efficiency (NUE) (Khanif and Pancras, 1990). The inefficiency of conventional nitrogen fertilizers poses a significant challenge in enhancing agricultural productivity sustainably.

In response to the need for improved nitrogen use efficiency, scientists have developed technologies aimed at enhancing the controlled release of nitrogen from urea fertilizers. These technologies include the use of coated urea, nitrification inhibitors, and biodegradable polymers, among others. Controlled-release urea (CRU) fertilizers offer the advantage of gradually releasing nitrogen, aligning with plant uptake patterns, and thereby reducing nitrogen losses and improving fertilizer NUE [3]. While various coating materials have been explored for their potential in enhancing NUE, factors such as high costs and associated risks have limited their widespread adoption [4,5,6]. Recent research efforts have focused on the development of environmentally friendly coating materials, including biodegradable polymers derived from biomass sources such as starch, cellulose, chitosan, and proteins. Starch-based superabsorbent polymers have gained attention for their potential in enhancing nutrient retention in soil and reducing leaching losses.

Maize, a versatile crop widely cultivated for food, feed, and forage purposes, stands to benefit from improved nitrogen utilization, given its high nitrogen requirements for optimal growth and yield. Considering these considerations, the present study was conducted with an objective the performance of different types of urea fertilizers, including coated urea and prilled urea, in terms of nitrogen mineralization and their impact on the growth and yield of fodder maize in *Alfisols* under laboratory conditions. This investigation seeks to contribute to the development of strategies for optimizing nitrogen use efficiency in fodder maize cultivation, thereby enhancing agricultural sustainability and productivity.

2. MATERIALS AND METHODS

Location: The study was conducted at the Department of Soil Science and Agricultural Chemistry laboratory and in a greenhouse at the College of Agriculture, V. C. Farm, Mandya, UASB (University of Agricultural Sciences, Bangalore) during the period of 2020-2021. Geographically, the field is situated at approximately 12°34' latitude and 76°49' longitude, with an altitude of 713 meters above mean sea level. The location falls within the Southern Dry Zone (Zone-6) of Karnataka.

Experimental Setup: The experimental setup included laboratory-scale investigations conducted in the Department of Soil Science and Agricultural Chemistry laboratory, as well as greenhouse trials at the College of Agriculture, V. C. Farm, Mandya. The laboratory experiments allowed for precise control and monitoring of variables, while greenhouse trials provided a simulated field environment to assess the performance of fodder maize under more realistic conditions.

Experiment I: The same soil sample collected for the greenhouse study was utilized for the incubation study. The physical and chemical properties of the soil are detailed in Table 1. Incubation studies were conducted using cups capable of holding 100 g of soil. Following the gathering of soil samples, the soil was treated with farmyard manure (FYM) at the recommended dose for fodder maize crops, with accurately 100 g of soil treated with FYM being transferred to each cup. Subsequently, precise quantities of different types of urea fertilizers were applied to the soil according to the treatment specifications. To prevent contamination and nitrogen loss, soil sampling was conducted destructively, necessitating the use of separate containers (Fig. 1) for each time interval (0, 1, 2, 3, 4, 5, 10, 15, 20, 25, 30, 35, 40, 45, and 50 days). Soil moisture levels were maintained at field capacity (FC) throughout the incubation period, with periodic replenishment of lost water occurring at 2-day intervals based on observed weight loss.

NH_4^+-N and NO_3^- -N: The 10-gram soil was drawn to a conical flask from each cup which was incubated at 0, 1, 2, 3, 4, 5, 10, 15, 20, 25, 30, 35, 40, 45, and 50 days (separate cups were maintained for each interval) and added with 100 mL of 2M KCl solution, Shaked for 30 minutes and filtered.

To determine NH4+-N and NO3- -N, 50 mL of filtrate was transferred to a distillation tube added with 0.5 g of MgO followed by digestion and distillation done to trap NH4+ in a receiving flask containing 4 percent boric acid with mixed indicators. Further, the receiver flask was titrated against 0.1N HCl and expressed as NH4+-N. However, to determine the NO3- -N, 0.50 g of Devarda’s alloy was added to the same digested sample further, repeated the above procedure then expressed as NO3- -N [7].

Fig. 1. Mineralization of different types of urea fertilizer kept at different intervals

Table 1. Initial physical and chemical properties of the soil used for laboratory incubation and green house experiments

Sl. no	parameters		Values
Physical properties			
1	Particle size distribution	Sand (%)	74.52
		Silt (%)	12.5
		Clay (%)	12.98
		Textural class	Sandy loam
2	Maximum water holding capacity (%)		52.5
3	Field capacity (%)		26.25
4	Bulk Density (g cm^{-1})		1.49
5	Particle Density (g cm^{-1})		2.51
Chemical properties			
1	pH (1:2.5)		8.12
2	EC (dSm^{-1})		0.27
4	OC (g kg^{-1})		6.92
5	Available Phosphorus (kg ha^{-1})		44.37
6	Available Potassium (kg ha^{-1})		365.16
7	Exchangeable Calcium [c mol (p+) kg^{-1}]		10.10
8	Exchangeable Magnesium [c mol (p+) kg^{-1}]		4.4
9	Available Sulphur (mg kg^{-1})		25.12
10	DTPA-Iron (mg kg^{-1})		9.16
11	DTPA-Copper (mg kg^{-1})		1.21
12	DTPA-Manganese (mg kg^{-1})		5.87
13	DTPA-Zinc (mg kg^{-1})		2.89
Treatments details:			
T_1	Control (Untreated soil)		
T_2	Urea (Uncoated)		
T_3	Prilled urea (Uncoated)		
T_4	Neem coated urea		
T_5	Neem coated prilled urea		
T_6	Corn starch based superabsorbent coated (@3%) prilled urea		
T_7	Corn starch based superabsorbent coated (@6%) prilled urea		
T_8	Physical blending of prilled urea + corn starch superabsorbent (13.44 kg ha^{-1})		
T_9	Physical blending of prilled urea + corn starch superabsorbent (27.17 kg ha^{-1})		

Fig. 2. Different types of urea fertilizers

Table 2. Experimental details

Crop	Fodder maize
Variety	African tall
Date of sowing	15.04.2021
Date of harvesting	03.06.2021
Duration	50 days
Design	CRD
Treatments and Replication	09 and 03
Fertilizers	150:75:75 (N, P_2O_5, K_2Okg ha^{-1}) and FYM (10 t ha^{-1})

Experiment II: A pot culture experiment was conducted to evaluate the impact of various types of urea fertilizers on the growth and development of fodder maize. The experiment was carried out in the greenhouse facilities in the Department of Horticulture at the College of Agriculture, V. C. Farm, Mandya. Nine distinct treatments were established and replicated three times, following a Completely Randomized Design (CRD) arrangement.

2.1 Statistical Analysis

The data pertaining to 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 Microsoft excel. Further the significant difference between treatments means were compared with critical differences at 5% confidence level.

3. RESULTS AND DISCUSSION

3.1 Ammonium Content at Different Days After Incubation

Ammonium content in soil as influenced by the application of different urea fertilizers showed non-significant during 0th DAI. Further, in CU treatment the NH_4^+-N content (30.00 µg per 100g soil) increased (76.00 µg per 100g soil) up to 5th DAI and gradually decreased (13.00 µg per 100g soil) till 50th DAI by revealing higher NH_4^+-N content in the initial among all the treatments and very low content at the end of incubation period. Similarly, prilled urea treated cup shown increased from 29.00 to 74.00 to 21.00 µg per 100g soil. Initially, the coated urea fertilizer showed less quantity of NH_4^+-N which increased till 10th DAI and then decremental rate was recorded till to the 50th DAI. Among the different coated urea fertilizer CSPC @3% was found to be superior over all the treatments. CSPC @3% NH_4^+-N content recorded at 28.00 mg per 100g soil which increased to 76.00 µg per 100g soil and decreased to 28.00 µg per 100g soil which was on par with neem coated urea increased from 28.00 to 75.00 and then decreased to 27.00 µg per 100g soil at 0th, 10th and 50th DAI followed by the neem coated prilled urea respectively. From the above results it was clear that the disappearance of urea-N and accumulation of maximum concentration of NH_4^+-N was much quicker in uncoated urea compared to coated urea in soil. This could be due to the rapid hydrolysis of urea to ammonium carbonate which is favourable for higher urease activity [8]. After reaching the maximum concentration in both coated and uncoated urea, NH_4^+-N the content declined possibly due to microbial immobilization of N which increased faster than the N mineralization resulting in decline in the amount of N-mineralized. Later, the decrease in NH_4^+-N content with progress of time might be due to nitrification, ammonia volatilization. Similar results were reported by Kenawy et al. [9].

3.2 Nitrate Content at Different Days After Incubation

A significant difference was observed among the treatments concerning NO3- -N content in soil from 1st day of incubation and, its content increased after every incubation period. Relatively higher NO3- -N content (29.00 µg per 100g soil) was found in T2 (CU) followed by T3 (PU), T8 (PSAC @3%), and T9 (PSAC @6%) with 25.00, 25.00 and 24.00 µg per 100g soil, respectively. The least NO3- -N content was recorded in treatment that received CSPC @3% (T6) with 17.00 µg per 100g soil which was on par with NCU (T4) with 17.00 µg per 100g soil, respectively. However, on the 50th day of incubation where in coated fertilizer treatment T6 showed a high NO3- -N content of 83.00 µg per 100g soil which was on par with T4 at 77.00 µg per 100g soil and the least NO3- -N concentration was detected in T2 (29.00 µg per 100g soil) followed by PU (38.00 µg per 100g

Table 3. Ammonium content in soil at different days after incubation as influenced by different types of urea fertilizers

Treatment	**NH_4^+ (µg per 100g soil)**														
	0th	**1st**	**2nd**	**3rd**	**4th**	**5th**	**10th**	**15th**	**20th**	**25th**	**30th**	**35th**	**40th**	**45th**	**50th**
	DAI														
T_1	27.00	29.00	36.00	45.00	56.00	63.00	58.00	51.00	46.00	42.00	36.00	26.00	20.00	14.00	11.00
T_2	30.00	38.00	47.00	56.00	68.00	76.00	62.00	54.00	49.00	46.00	39.00	30.00	23.00	16.00	13.00
T_3	29.00	37.00	45.00	54.00	66.00	74.00	66.00	58.00	53.00	49.00	42.00	33.00	25.00	19.00	18.00
T_4	28.00	29.00	38.00	49.00	60.00	68.00	75.00	65.00	62.00	59.00	49.00	38.00	34.00	29.00	27.00
T_5	29.00	30.00	40.00	51.00	62.00	70.00	72.00	62.00	59.00	56.00	46.00	36.00	32.00	26.00	25.00
T_6	28.00	29.00	37.00	47.00	59.00	67.00	76.00	66.00	63.00	60.00	50.00	39.00	35.00	30.00	28.00
T_7	29.00	32.00	41.00	51.00	63.00	69.00	71.00	63.00	58.00	55.00	47.00	35.00	31.00	25.00	24.00
T_8	29.00	36.00	43.00	52.00	65.00	72.00	68.00	60.00	55.00	52.00	44.00	35.00	27.00	22.00	21.00
T_9	29.00	37.00	44.00	53.00	65.00	73.00	67.00	59.00	54.00	51.00	43.00	34.00	26.00	21.00	20.00
S. Em. ±	**1.21**	**0.20**	**0.35**	**0.37**	**0.34**	**0.37**	**0.51**	**0.54**	**0.45**	**0.44**	**0.38**	**0.33**	**0.31**	**0.50**	**0.37**
CD @ 1%	**NS**	**0.98**	**1.75**	**1.86**	**1.68**	**1.85**	**2.56**	**2.71**	**2.25**	**2.19**	**1.89**	**1.63**	**1.56**	**2.52**	**1.98**

Table 4. Nitrate content in soil at different days after incubation as influenced by different types of urea fertilizers

Treatment	**NO_3^--N (µg per 100g soil)**														
	0th	**1st**	**2nd**	**3rd**	**4th**	**5th**	**10th**	**15th**	**20th**	**25th**	**30th**	**35th**	**40th**	**45th**	**50th**
	DAI														
T_1	15.00	17.00	24.00	33.00	44.00	48.00	49.00	45.00	40.00	38.00	33.00	28.00	23.00	22.00	19.00
T_2	18.00	29.00	36.00	44.00	57.00	64.00	86.00	96.00	102.00	62.00	56.00	48.00	38.00	33.00	29.00
T_3	17.00	25.00	33.00	42.00	54.00	61.00	80.00	93.00	98.00	70.00	65.00	57.00	47.00	43.00	38.00
T_4	16.00	17.00	26.00	37.00	47.00	52.00	70.00	76.00	87.00	95.00	89.00	84.00	81.00	78.00	74.00
T_5	17.00	19.00	28.00	39.00	50.00	55.00	73.00	79.00	90.00	92.00	85.00	78.00	72.00	63.00	59.00
T_6	16.00	17.00	25.00	35.00	45.00	51.00	69.00	75.00	86.00	98.00	92.00	89.00	89.00	85.00	83.00
T_7	17.00	20.00	29.00	39.00	51.00	56.00	74.00	86.00	91.00	89.00	82.00	71.00	68.00	59.00	56.00
T_8	17.00	24.00	31.00	40.00	54.00	60.00	77.00	91.00	95.00	79.00	71.00	63.00	54.00	50.00	45.00
T_9	17.00	25.00	32.00	41.00	54.00	61.00	79.00	93.00	96.00	75.00	68.00	61.00	50.00	47.00	42.00
S. Em. ±	**0.70**	**0.40**	**0.31**	**0.33**	**0.43**	**0.47**	**0.59**	**0.60**	**0.57**	**0.59**	**0.74**	**1.36**	**2.19**	**2.01**	**1.88**
CD @ 1%	**NS**	**1.99**	**1.56**	**1.63**	**2.13**	**2.37**	**2.97**	**2.99**	**2.87**	**2.95**	**3.70**	**6.82**	**8.92**	**8.19**	**7.64**

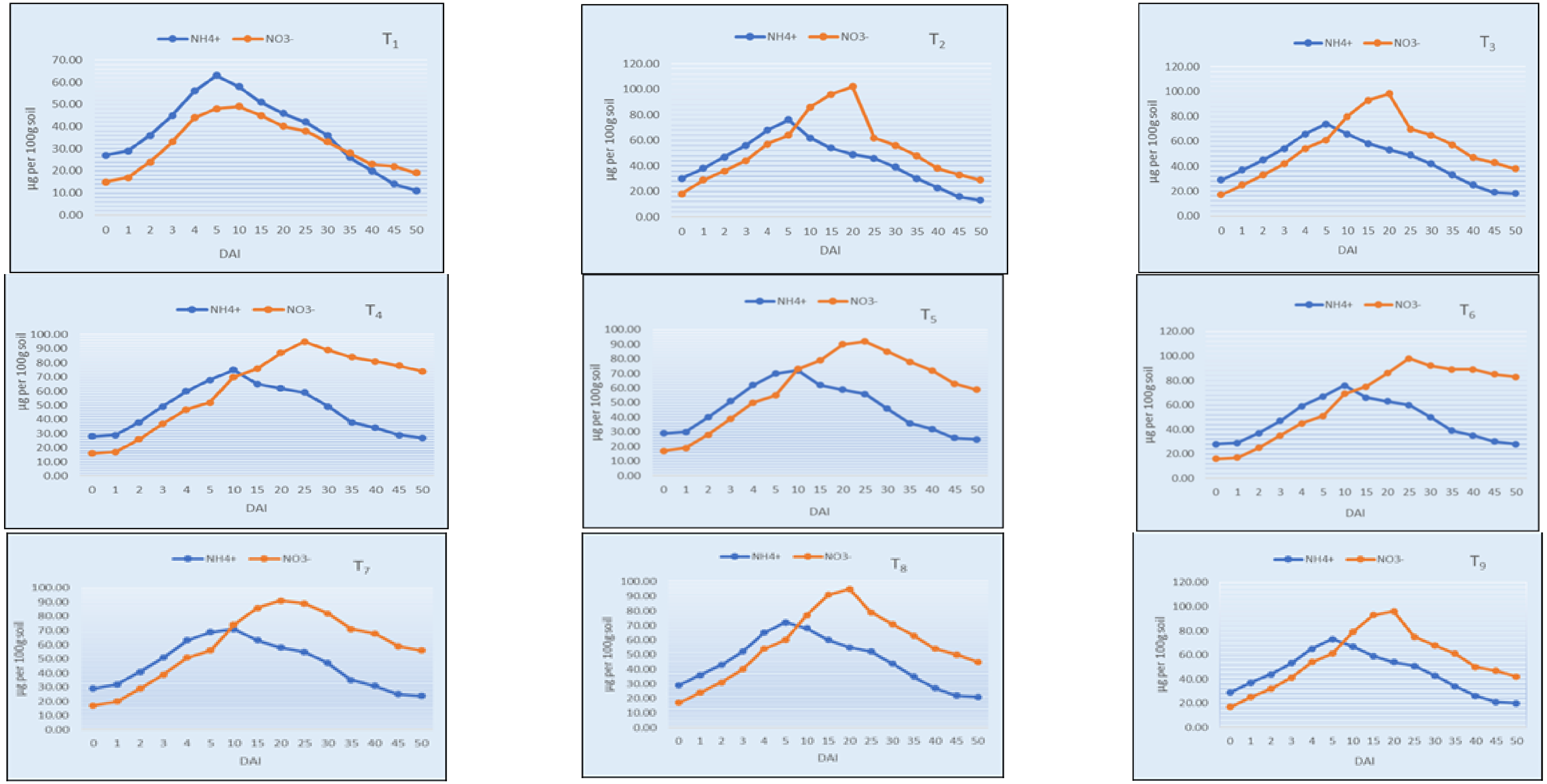

Fig. 3. Release pattern of different types of urea fertilizer

soil). In control the least amount of NO3- -N (19.00 µg per 100g soil) content was observed compared to all the treatments in all successive incubation periods. Coated urea fertilizers release less nitrate nitrogen in the initial period but it continues to till 50th DAI with increased pattern. In uncoated urea (CU and PU) more release was observed in the initial period of incubation days up to 45 DAI after that it decreases. Hence coated urea is better to release NO3- -N steadily for a longer period of incubation [10]. The release pattern of NO3- -N as influenced by different coated urea fertilizers is of major concern for minimizing nitrogen losses through leaching and can increase the use efficiency by crops. From the results, it was found that coated urea fertilizers prevented the immediate urea hydrolysis and release of NH4+-N compared to uncoated urea application [11]. Also, the conversion of NH4+-N to NO3- -N was prolonged through nitrification inhibition. In the present investigation the production of NO3- -N showed a gradual increase as a function of incubation time even in the soil which did not receive any urea application [12]. This might be due to the presence of easily oxidizable nitrogen (available-N) which released nitrogen during the incubation period.

3.3 Effect of Different Types of Urea Fertilizers on Growth Parameters of Fodder Maize

Plant height: The plant height of fodder maize varied significantly among different treatments. At 15 DAS, the treatment, T2 (CU) recorded the highest plant height (39.25 cm) followed by T3 (PU), which recorded 37.59 cm plant height, respectively. The lower plant height of 27.92 cm was recorded in control followed by T6 (CSPC @3%) and T4 (NCU), with 33.14 and 33.26 cm recorded respectively. Further, at 30 DAS, the plant height was recorded highest in T6 (94.57 cm) which was on par with T4 (93.29 cm), and the lowest plant height was recorded in T1 (78.68 cm) followed by T2 (81.82 cm). A completely different pattern of plant height was observed among the treatments at the harvest stage. The highest plant height of 170.67 cm was recorded in T6 (CSBA @3%) and it was on par with T4 (NCU) with 169.56 cm. The lowest plant height was noticed in the control (97.85 cm) which did not receive any urea fertilizer. The apical meristem is responsible for vertical growth, and organ increase in length of a stem. For stimulation of plant growth hormones, the supply of water and nutrients through the ideal root system becomes inevitable. The increase in plant height with different nitrogen sources can be attributed to the fact that nitrogen promotes plant growth, and increases the number and length of the internodes which results in a progressive increase in plant height.

Number of leaves per plant: The number of leaves was found to be significantly influenced by different urea fertilizers at all the stages of growth *i.e.* at 30 DAS and harvest, except at 15 DAS where the effect of different urea fertilizers on several leaves was found to be non-significant. At 30 DAS, a maximum number of leaves were recorded by the treatment CSPC @3% (T6- 6.12) which was on par with NCU (T4-6.02) followed by NCPU (T5-5.79) and showed significantly superior over other treatments. The lowest number of leaves (4.18) was recorded by the control. At harvest, a maximum number of leaves (10.79) were recorded with the application of CSPC @3% which was found significantly superior over the rest of the treatments followed by NCU (10.33). However, CU (8.07) and control (7.18) recorded the lowest number of leaves. The increase in plant height with CSPC @3% and NCU might be due to a steady release pattern with synchronized plant demand [13] might have enhanced synthesis of chlorophyll, induced cell division, and cell expansion leading to stimulated cell elongation along the main axis, which increased in number and length of internodes and the resultant increase in plant height [14]. Jhones et al. [15] found that nitrogen fertilization, significantly increased the number of leaves and they suggested that the increase in a number of leaves may be because of an increasing number of nodes. NO3- -N is negatively charged and does not accumulate in the soil. It moves freely in the soil solution, so it can be absorbed by plants, but it can also be leached easily. NH4+-N can be adsorbed on minerals and organic matter and it may compete with other cations that are important for plant nutrition [16]. However, the rapid hydrolysis of urea causes serious nitrogen losses. Thus, due to the continued nitrogen release by CSPC @3% and NCU, the contents of NO3- -N and NH4+-N increased significantly compared to those in the uncoated urea treatments [17].

Leaf area: Expansion of leaves, both horizontally and vertically is preferable during the crop growth period. It also indicates the status of soil physical properties and root proliferation along with its potential to provide balanced nutrients. As far as deflection in mean leaf area due to various fertilizer treatments is concerned, it is obvious from the data that at 15 DAS, there were significant changes in leaf area per plant. At this stage, the maximum leaf area of 426.51 cm2 was noted with CU (T2) followed by PU (T2 -382.32 cm2). The lowest leaf area per plant was recorded with treatment CSPC @3% (T6 -281.67 cm2) and control (T1 -233.54 cm2). However, at 30 DAS, there was a pronounced effect of different urea fertilizers with maximum leaf area contained in T6 (815.50 cm2) which is on par with T4 (806.68 cm2) followed by T5 (780.30 cm2). The lowest leaf area per plant was recorded with treatment T1 (585.45 cm2) and T2 (637.78 cm2). A similar trend was observed at the harvest stage. The maximum leaf area (1870.83 cm2) was recorded by T6 and it was on par with T4 (1850.59 cm2) followed by treatments T5 (1793.06 cm2) and T7 (1760.92 cm2), while, T2 (1670.98 cm2) and T1 (1540.34 cm2) recorded lowest leaf area. However, due to the slow release of CSPC @3% and NCU which synchronizes with the crop nutrient critical growth stage and influences the plant height, number of leaves per plant as well as the leaf area. The coated superabsorbent *i.e*., CSPC @6% might have more dissolution and result in a high release of nitrogen at an early stage of incubation leading to higher plant height and number of leaves per plant in the initial day and least at harvest.

3.4 Effect of Application of Different Urea Fertilizers on Yield and Quality Parameters of Fodder Maize

Green fodder yield (GFY): Application of urea fertilizers recorded significant enhancement in GFY. The maximum GFY of 343.29 g plant-1 was observed in T6 which received CSPC @3%. The next best treatment was T4 which received NCU (328.25 g plant-1) followed by T5 which received NCPU (276.06 g plant-1) and these are superior over T3 PU (267.04 g plant-1), T2 CU (246.26 g plant-1) and control (207.88 g plant-1).

Dry fodder yield and dry matter percentage: The dry matter content varied significantly among the treatments. However, the highest dry fodder yield was recorded in CSPC @3% (T6) 213.65 g plant-1 and it was followed by 198.61 and 162.45 g plant-1 in T4 (NCU) and T5 (NCPU), respectively. The lowest dry matter content of 78.28, 116.35, and 137.40g plant-1 was noticed in control, CU, and PU, respectively. A similar trend was observed with dry matter percentage.

However, the dry matter percent of fodder maize was followed in the order of T6> T4>T5>T8>T7>T9>T3>T2>T1 with 57.75, 54.52, 52.15, 50.75, 49.59, 49.11, 48.53, 44.32 and 34.38 percent, respectively.

The increase in fresh yield of forage under nitrogen application can be attributed to the positive effect of nitrogen on all the growth parameters investigated in this study [18]. The high moisture content of the forage may be due to increased soil water retention and urea use efficiency as superabsorbent coated urea reduces urea loss which helps in the utilization of soil nitrogen by plants for their better growth and yield. A similar result was obtained by Joshi et al. [19].

The productivity efficiency of fodder maize is governed by growth parameters [20]. The beneficial effect of CSPC @3% and NCU decreases nitrogen losses and provides a slow release of nitrogen to the plant. Similar results on yield components have also been reported by Ullah et al. [13]. Higher recovery of nitrogen may be possible when the nitrogen is made available to the plant over longer periods and by reducing nitrogen losses. Similarly, the dry fodder yield and dry matter percentage were also increased significantly with the advancement in maturity and harvesting times. If there has been higher fodder yield then it is quite obvious to have higher dry matter per cent. Absorption of water and nutrients from soil plays a vital role in determining the production efficiency of fodder maize [21]. The factors might have synergistically acted on improving nutrient uptake, promoting various metabolic processes resulting in increased plant growth and fodder yield [22].

Crude protein: The results revealed that crude protein percent was significantly affected by different urea fertilizers. Maximum crude protein content (4.08 %) in fodder maize was recorded by CSPC @3% (T6) and found significantly superior to the rest of the treatments and being statistically at par with the NCU (T4 -4.03 %). The lowest crude protein content was recorded with control (2.25 %), CU (2.88 %), and PU (3.22 %). From the results, it can be concluded that crude protein percent in plants was found to increase with the increase in N content in plants.

Table 5. Effect of application of different types of urea fertilizer on growth parameters of fodder maize

Treatment	Plant height (cm)			Number of leaves			Leaf area		
	15th Day	30th Day	At harvest	15th Day	30th Day	At harvest	15th Day	30th Day	At harvest
T_1	27.92	78.68	97.85	2.06	4.18	7.18	233.54	585.45	1540.34
T_2	39.25	81.82	113.38	2.16	5.08	8.07	426.51	637.78	1670.98
T_3	37.59	84.61	131.17	2.13	5.25	9.93	418.39	677.76	1715.71
T_4	33.26	93.29	169.56	2.06	6.02	10.33	309.98	806.68	1850.59
T_5	35.05	90.58	158.53	2.11	5.79	9.88	333.39	780.30	1793.06
T_6	33.14	94.57	170.67	2.05	6.12	10.79	281.67	815.50	1870.83
T_7	35.15	89.48	157.80	2.13	5.68	9.33	348.69	757.73	1760.92
T_8	36.12	87.55	143.26	2.14	5.42	9.06	370.86	721.87	1735.29
T_9	36.26	86.44	139.58	2.13	5.33	8.95	382.32	713.13	1736.26
S. Em. ±	**0.47**	**0.59**	**1.59**	**0.12**	**0.03**	**0.07**	**5.07**	**3.83**	**6.27**
CD @ 1%	**1.92**	**2.41**	**6.47**	**NS**	**0.13**	**0.29**	**20.62**	**15.58**	**25.53**

Table 6. Effect of application of different types of urea fertilizer on yield and quality parameters of fodder maize

treatments	Green fodder yield (g plant^{-1})	Dry fodder yield (g plant^{-1})	Dry matter percentage	Crude protein (%)	Total ash content (%)	Organic matter content (%)
T_1	207.88	78.28	34.38	2.25	2.12	97.88
T_2	246.26	116.35	44.32	2.88	2.75	97.25
T_3	267.04	137.40	48.53	3.22	2.91	97.09
T_4	328.25	198.61	54.52	4.03	3.82	96.18
T_5	276.06	162.45	52.15	3.88	3.55	96.45
T_6	343.29	213.65	57.75	4.08	3.91	96.09
T_7	269.80	158.82	49.59	3.75	3.42	96.58
T_8	265.25	135.61	50.75	3.52	3.29	96.71
T_9	284.25	154.61	49.11	3.39	3.17	96.83
S. Em. ±	**6.78**	**4.31**	**0.23**	**0.04**	**0.03**	**4.16**
CD @ 1%	**27.60**	**17.56**	**0.94**	**0.14**	**0.13**	**NS**

Ash content (%): The total ash percent content in fodder maize was influenced by different urea fertilizers. The highest total ash (3.91%) was observed with CSPC (T6), which was significantly higher than the rest of the treatments and was statistically on par with NCU (T4) treatment (3.82 %) followed by treatment NCPU (T5- 3.55%). However, the lowest ash content was observed in control (T1-2.12%), CU (T2-2.75 %), and PU (T3-2.91%).

Organic matter content (%): However, the highest organic content of fodder maize was found in untreated treatment (97.88 %) followed by T2 (97.25 %) which received CU. Further, the OM content followed in the order of T3 > T9 > T8 > T7 > T5 > T4 > T6 with (97.09 > 96.83 > 96.71 > 96.58 > 96.45 > 96.18 > 96.06, respectively) which received PU, PCSA @6%, PCSA @3%, CSPC @6%, NCPU, NCU and CSPC @3%, respectively.

Crude protein contents have a major role in increasing the quality of fodder crops. From the result so obtained it can be concluded that crude protein percent in plants was found to increase with increased levels of N in plants [23,24]. This result emphasized the fact that being a structural component of amino acids, nitrogen plays a greater role in protein synthesis [25]. The increased content of protein in neem-coated and corn starch-based superabsorbent coated urea was attributed to the enhanced nitrate reductase activity and increased N availability in the soil caused by the slow-release behavior of coated urea fertilizer [26].

Ayub et al. [27] reported that the application of nitrogen to maize increases the nutritive value by increasing crude protein and by reducing ash fiber concentration of crude protein increasing crude protein content may be because nitrogen often plays a great role in the synthesis of protein. The maximum nitrate content achieved in CSPC @3% and NCU caused an effect on ash content and organic matter [28]. Nitrogen supply to the crop throughout the growing season significantly increases crude protein, crude fiber, and total ash percent in plants.

4. CONCLUSION

The study observed significant differences in ammonium (NH_4^+-N) and nitrate (NO_3^- -N) content in soil among different urea treatments over time. Coated urea fertilizers exhibited slower release patterns compared to uncoated urea, resulting in reduced NH_4^+-N and NO_3^- -N concentrations initially but prolonged release over time. This controlled release is advantageous for sustaining plant nutrient uptake and minimizing nitrogen losses through leaching and volatilization. The application of urea fertilizers significantly influenced the growth parameters of fodder maize. Coated urea treatments, particularly CSPC @3%, demonstrated superior performance in terms of plant height, number of leaves, and leaf area compared to uncoated urea and control. This indicates the effectiveness of coated urea formulations in providing a sustained nitrogen supply, promoting plant growth, and enhancing vegetative biomass production. It also found substantial improvements in green fodder yield (GFY) and dry fodder yield with the application of urea fertilizers, particularly CSPC @3%, which resulted in the highest GFY and dry matter content. The enhanced yields can be attributed to the optimized nitrogen availability provided by coated urea formulations, leading to improved nutrient uptake, biomass accumulation, and ultimately, higher forage productivity. controlled-release characteristics of coated urea fertilizers, as evidenced by the gradual release of NH_4^+-N and NO_3^- -N over time, contribute to enhanced nitrogen use efficiency. By reducing nitrogen losses through leaching, denitrification, and volatilization, coated urea formulations offer a sustainable approach to fertilizer management, ensuring optimal nutrient utilization by crops while minimizing environmental impact. It provides valuable insights into the efficacy of coated urea fertilizers in optimizing nitrogen use efficiency and enhancing the productivity of fodder maize. These findings have significant implications for improving fertilizer management practices, promoting agricultural sustainability, and addressing global challenges related to food production and environmental stewardship.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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